WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

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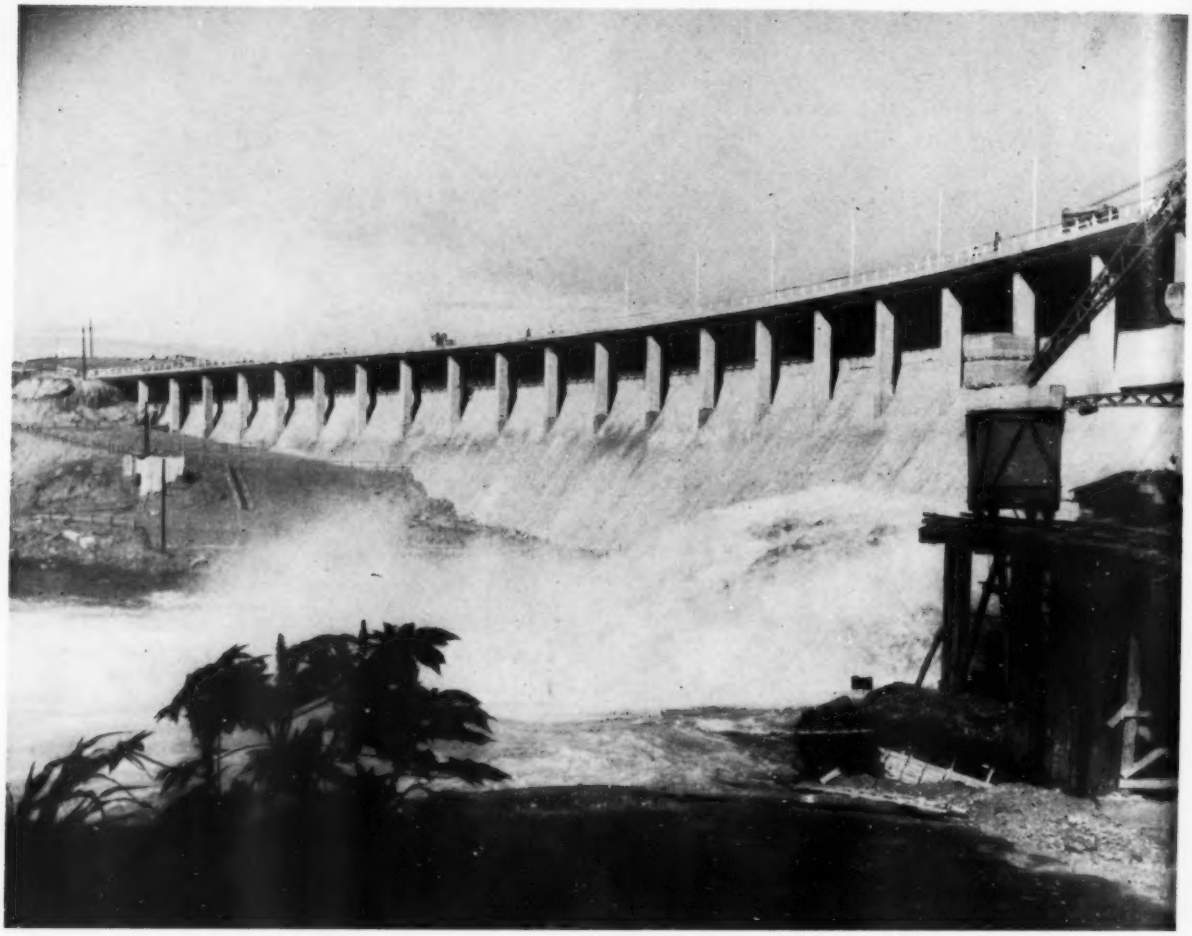

The Owen Falls Hydro-electric Scheme will ultimately provide 700 million units of electricity a year, bringing light and power to many parts of East Africa.

The many miles of power, distribution and control cables required for the first four generators of this great scheme were supplied by BICC and installed by the BIC Construction Company — Members of the BICC Group. One hundred and twenty route miles of 132kV overhead line are being erected by the same Company to carry power to Tororo and Kampala.

This contract for the Uganda Electricity Board is typical of the work carried out by the BICC Group in power transmission and distribution, in many parts of the World.

Consulting Engineers: Kennedy & Donkin
Sir Alexander Gibb & Partners

BICC

TRANSMISSION EQUIPMENT at OWEN FALLS

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Reducing the Cost

IN recent years a great deal of attention has been paid to paring down the cost of the civil-engineering works involved in large hydro-electric projects, and among the methods adopted for this purpose two aspects may be singled out as being of particular importance. First, the surveying methods used in these days are vastly more efficient than those of a couple of decades ago. The geologist has invoked the aid of the physicist to create instruments capable of much greater accuracy than has ever been possible before, and in addition there is now the possibility of using automatic computing engines to interpret, rapidly and accurately, a vast series of experimental results. These improvements have rendered the whole surveying process at once more economical and more certain than in the past. There are cases in Europe of sites that have been examined time and again in previous years, but for one reason or another have been rejected as being unsuitable for hydro-electric development. In some cases it has been thought that the firm foundation for the dam would be jeopardised by the presence of fissures penetrating an unknown distance, and the relatively rudimentary grout-injection techniques of earlier days could not be relied on to render them safe or watertight.

The second major aspect of cheapening hydro-electric construction relates to the improvement in what may now be called almost a separate branch of engineering—the laying out of the construction works to avoid the employment of an excessive labour force, to prevent stoppages due to inadequate or unsuitable equipment, and to accelerate the rate of excavation and concrete pouring to figures that would legitimately have astonished engineers of barely a generation ago.

Dams have tended to increase in size, and the world demand for electrical energy has increased, so that small developments are no longer worth contemplating unless there are special local circumstances. This has meant, for example, that the cost of doubling the single concrete-mixing equipment which would be required to maintain the normal schedule is an expenditure, in relation to the whole cost of the project, that can be accepted. If this is done, it means that there is practically no likelihood of breakdown, since one half of the plant can maintain the desired flow of concrete.

In regard to excavation work, hand excavation and the use of the steam shovel are nowadays completely outmoded, and every year new and more efficient types of earth-moving equipment become available, generally powered by internal-combustion engines, to carry out such processes as digging, clearing scrub, loading spoil and actual excavation. The universal handmaiden of the civil engineer engaged in this work, of course, is the bulldozer, and in its various forms it has almost ousted every other comparable method of handling soil and rock. The use of pneumatic tyres on earth-moving equipment has given these machines an ever-increasing flexibility in operation and a much greater speed when moving from site to site.

The contractor's light railway, once a feature of every major construction site, is now seldom seen. The telpher line or the belt conveyor for aggregate and sand nowadays takes its place, and the expensive levelling, track repairing, and maintenance work associated with light railways is no longer necessary. The dumper can follow the excavating machinery wherever it goes, and can perform miracles of movement in mud, over rocky ground or on steeply-sloping terrain. The telpher line and the *blondin*, which is frequently used to carry hoppers of as much as eight cubic yards capacity, is nowadays remotely controlled from a single point, in touch by short-wave radio with every working area on the site. The accident rate steadily declines as fewer but more skilled men are employed.

The use of various special materials for addition to the concrete mix has enabled pouring to be carried out in cold weather which, a few years ago, would have prevented work being carried on at all. In this way, expensive delays due to frost are avoided. A greater knowledge of cement chemistry has enabled accurate predictions to be made of the heat rise on setting, and the shrinkage, so that concrete can be

poured up to the maximum permissible amount with absolute knowledge of the conditions that are likely to follow, rather than the inspired guesswork of previous years. The concrete used nowadays is of the plastic nature, which has meant that a great attention has had to be paid to the pouring equipment itself. The old type of wet concrete could be handled by chutes or even conveyor belt or pipe. Now the use of buckets is almost universal, and with perfect electrical control, co-ordinated and interlocked in such a way as to prevent any danger of maloperation, concrete pouring rates of over 7,000 cubic yards a day have been achieved.

The shuttering has been the subject of much attention, and steel forms or even prefabricated concrete blocks have been used successfully to expedite the erection, striking and re-erection of the shuttering sections. Internal vibrators, operating at high frequencies, no longer need to be attached to the shuttering sections, but operate directly in the concrete, increasing its strength and homogeneity.

We have mentioned only two of the methods whereby hydro-electric construction has been cheapened—better and more accurate surveying methods and more efficient construction equipment—although there are many other aspects of this work in which progress has been made. For example, the mass gravity type of dam is being superseded by the arch type wherever possible, with an enormous reduction in the amount of concrete necessary.

The hydro-electric engineer still has a very great task to fulfil, in spite of the onset of atomic energy. In the recent presidential address to the Institution of Electrical Engineers in London, Mr. J. Eccles, C.B.E., B.Sc., M.I.C.E., M.I.Mech.E., M.I.E.E., mentioned that the world total of inland water power, 40 per cent. of which is in Africa, could supply at least three-quarters of man's present energy requirements. French sources have recently given figures that are of a comparable order. If the cost per kilowatt can be brought down still further, hydro-electric energy will compete whatever the future holds in regard to the generation of power.

Design of Pressure Shafts

WHILE this issue of WATER POWER is in the press an important paper will be read before The Institution of Civil Engineers by Dr. Charles Jaeger entitled "Present Trends in the Design of Pressure Tunnels and Shafts for Underground Hydro-Electric Power Stations." Recent advances in tunnelling technique have given a great impetus to the development of the underground power station, and the design of pressure tunnels and shafts has assumed great importance. Dr. Jaeger has done a great deal of work on the relationship of the stress patterns in the rock to pressure-shaft design, and in his paper he expounds the latest views on strain and stress distribution in the rock round a pressure tunnel and in the linings of steel-lined shafts. It is now generally accepted that rock in its natural state is prestressed by its own weight, and modern research work seems to prove that the stress distribution is of the so-called "hydrostatic" type, with the stresses at a point being equal in any direction. When a tunnel is cut in such a "prestressed" rock, stresses will develop round the tunnel which disturb the existing stress distribution. If the tunnel is filled with water and subjected to internal pressure, a new distribution of stresses arises. The two sets of strains and stresses —the first caused by the boring of the tunnel in prestressed rock; the second by subjecting the water in the tunnel to pressure—are explained in the paper, and their interaction analysed.

In the progress of this analysis, it soon becomes clear that proper grouting of the rock behind the concrete lining is an essential factor for the stability of the tunnel. Apart from the greater imperviousness attained, the modulus of elasticity of the rock is increased—the rock becoming more homogeneous and the concrete lining being prestressed.

Detailed information is given in the paper on the more important pressure shafts and on new underground power stations. The dimensions of the shafts, the stresses in the steel linings (and in the rock for many of them), and the main dimensions of some important power stations are summarised in tables and diagrams.

Turbines for Table Rock Dam

THE U.S. Army Corps of Engineers have announced that the contract for two 68,000 nominal horsepower 128·6 r.p.m. vertical-shaft single-runner Francis-type water turbines for the Table Rock Dam power station, Arkansas, has been placed with the English Electric Export and Trading Co. Ltd. The turbines are to be suitable for operating at heads of 134 to 228 ft., the nominal head being 190 ft. At 134 ft. head the output of each turbine is 44,000 h.p. and at 228 ft. it is 83,200 h.p. Delivery will commence in August 1956 and the equipment is due for completion by September 1957. The turbines will be made by The English Electric Co. Ltd. at their works in England.

This company's tender of $1,066,662, which has survived the requirements of the Buy American Act against four American tenders, was nearly $145,000 below the nearest American bid. The award has been welcomed by British industrialists, who feel that the more liberal trading policy it envisages is in the best long-term interests not only of Great Britain but also of the United States.

Further Expansion at Kitimat

THE capacity of the new aluminium smelter at Kitimat, British Columbia, will be immediately expanded to produce an additional 60,000 tons of aluminium ingot per year to meet the expected increase in near-term demand for the company's aluminium products. Authorisation has been given for the engineering staffs of Aluminum Company of Canada Limited to proceed with the ordering and installation of a fourth generator of 140,000 h.p. capacity for the Kemano power house and with the construction of additional smelter facilities at Kitimat which will increase by 65 per cent. the present rated capacity of the aluminium plant. Estimated fixed capital requirements of the new B.C. expansion programme, excluding alumina facilities, are approximately $45 million to be expended in 1955 and 1956, and it is proposed to increase the authorised capital of Aluminium Limited from 10,000,000 to 20,000,000 no-par-value shares.

In announcing the decision to expand in British Columbia, Mr. Davis, President of Aluminium Limited, noted that most of the basic hydraulic com-

ponents of the project, such as the main storage dam, the power tunnel and penstocks through the coastal mountains, and the 50-mile transmission lines, had already been built to support an aluminium capacity at least three times the size of the initial plant. For this reason the new additional facilities will have a much lower unit capital cost than in the existing smelter, which will improve the economics of the overall operation.

The company announcement said that market studies made during recent months show that demands for the company's aluminium ingot exceed the supply available from present production and should continue to increase throughout the coming years.

Glascarnoch Tunnel Broken Through

THE driving of the five miles long Glascarnoch tunnel, part of the North of Scotland Hydro-Electric Board's Conon Valley Scheme, was completed on Saturday, October 30, when Sir Hugh Mackenzie, C.B.E., Deputy Chairman of the Board, fired the final blasting charge. The Glascarnoch tunnel, which is 10 ft. in diameter, will carry water from a new loch formed in the valley of the River Glascarnoch by a dam near Aultguish, Ross-shire, to a 24 MW generating station on the shores of Loch Luichart 530 ft. below. The contractors are A. M. Carmichael Limited, Edinburgh, and the civil-engineering consultants are Sir Alexander Gibb & Partners.

Financing Electricity Supply in Europe

THE Organisation for European Economic Co-ordination has published the results of a most useful study of electricity-supply finances in a report entitled "The Price of Electricity and its Relation to Investment in the Electricity Supply Industry." The study has been based on figures from European countries covering the years up to 1952, and although the temptation to draw sweeping conclusions has been wisely avoided, attention is drawn to some important characteristics of the situation.

The unsettled transitional period following the war may now be regarded as over, and there is a steady annual increase in the demand for power of 6-7 per cent., equivalent to doubling the demand every 10-12 years. But in spite of the very large effort made, production capacity in some countries is still insufficient to meet demand and provide an adequate margin of reserve. The downward trend in real cost per kWh due to technical advances is slowing down, and the prospect of an increase in real cost per kWh must be envisaged.

The problem of financing the electricity-supply industry is a very special one, as the capital investment is much higher, and the turnover much lower, than is normal for other industries, and it is unlikely that the revenue will ever yield more than a fraction of the capital resources required to finance development. Consequently a very great part of these resources will have to come from the capital market or from public funds.

Unfortunately, since the war it has been difficult to procure sufficient capital due to the reduction of private savings, currency devaluations, the economic policies adopted by some governments, and the smallness of the national income of certain countries in comparison with the capital they require. For these reasons there is a danger that the development of electricity supply may be restricted, with serious economic consequences. In the light of this situation two conclusions are submitted: (a) the electricity-supply industry should be allowed sufficient freedom to be run on sound economic principles so that the raising of the capital required may be facilitated; and (b) in countries where imports of foreign capital are supported by governments, encouragement to these imports should be given by promoting a rate policy that will produce a commercial yield large enough to give the foreign investor a return comparable to that obtainable on the international capital market.

Portuguese Progress

A DISTINCT advance in the dates originally fixed for the completion of the hydro-electric power stations under the Portuguese Government's development plan is reported. The Cabril project scheduled to begin working in 1955 is already running experimentally and will have an annual output of 270 million kWh. Canicada, also due for completion next year, will be working this year and will add some 200 million units to the nation's supply. Bouca, which will complete the project for the harnessing of the Zezere, will start production in the second half of next year.

In the first three years of the development plan, the following leading hydro-electric schemes will have been completed: Salamonde (120 million units yearly), Cabril (270), Canicada (200), Bouca (135), and increase of output in other centres (80). Total production increase amounts to 805 million kWh.

Shawinigan Contracts

THE Shawinigan Engineering Co. Ltd. has completed the new crossing over the St. Lawrence River at Quebec and the new transmission lines from Quebec to Chaudière and from Chaudière to Beauceville. Work on the new La Tuque-Trois-Rivières transmission line is proceeding according to schedule. The company has also been awarded two important contracts: one to do the consulting engineering and design on the New Brunswick Electric Power Commission's generating plant at Beechwood on the St. John River; the other to carry out a topographical and general survey of the potential hydro-electric development of Grand Falls on the Hamilton River in Labrador for the British Newfoundland Corporation Limited. About 60 men are already working on the latter project.

Volta River Model

A MODEL of the Volta River has been constructed by George Wimpey & Co. Ltd. for the use of the consulting engineers, Sir William Halcrow & Partners, in determining the basic data required for the design of the dam, power station and ancillary works for the Volta River scheme. It is modelled to a horizontal scale of 1 : 1,000 and a vertical scale of 1 : 125 and covers a 30-mile stretch of the river. It is 150 ft. long and 30 ft. maximum width. To comply with the rapid construction schedule desired by the consulting engineers the contractors completed the moulding of the river bed in six weeks from setting the first profile.

Book Reviews

Vízeröhasznosítás (Water-Power Development), Vol. II, by Dr. Emil Mosonyi. Published by the School-Book Publishing Section of the Hungarian Ministry of Education. Printed by Budapest University Press, 7 in. by 9½ in., 376 pp., 181 ft., 85 plates with 182 photographic illustrations, and five folded diagrams. Price in Hungary, paper-wrappered 91·00 florins, paper-board bound 112·00 fl.

In the second volume of this comprehensive work on water-power development, the numbering of pages, chapters, paragraphs and figures begins where it ended in Vol. I. More than half the volume is devoted to high-head plants, and this section of the work covers all the types of installation and the various layouts occurring in actual practice. The chapter on penstocks, which is both exhaustive and up-to-date, extends to no less than 68 pages. The section dealing with storage pumping plants is also worth singling out. An extensive bibliography and a general index appear at the end of this volume, which, on the whole, presents the qualities and failings of Vol. I, as reviewed in our issue of January 1954, p. 27. These failings do not, however, detract from the intrinsic merits of the work, for which full credit must be given to both author and publisher. It is to be regretted that the language makes it so largely inaccessible to English readers.

Stauanlagen und Wasserkraftwerke (Dams and Water-Power Plants), by Dr. Ing. Heinrich Press, Professor at the Berlin-Charlottenburg Technical University. Published by Wilhelm Ernst & Sohn, Berlin-Wilmersdorf. Three volumes 6½ in. by 9½ in. Distributed in the United Kingdom by Lange, Maxwell & Springer Ltd., Maxwell House, 242, Marylebone Road, London, N.W.1. Price, cloth-bound 52s. 6d. each.

Vol. I. **Talsperren** (Storage Dams), VIII-212 pp., 326 ff, 1953, is divided into three main sections: 1, General aspects (definitions, purposes, sites, selection of appropriate dam type, etc.); 2, Masonry and concrete dams; 3, Earthfill and rockfill dams. As masonry dams are now rather an exception, the main stress in part 2 is laid on concrete structures—gravity dams, the various types of arch dam (including thin arches of the dome and shell pattern), buttressed and multiple-arch dams, together with their various methods of calculation. These are dealt with from all angles in separate chapters, short subsections being devoted to the heightening of existing dams, and to underground dams. Though rather brief, the section on dam constructional sites and their equipment covers all essentials. The hydraulic equipment of concrete dams (flood-control installations, bottom outlets, control and regulating gates, etc.), is reviewed and discussed in three sections, and there is a short chapter on dam supervision and control measurements. Earthfill and rockfill dams are treated in part 3 in the same manner and with the same thoroughness as concrete structures.

Vol. II. **Wehre** (River Barrages), VIII-204 pp., 326 ff., 1954. While "Talsperre," literally meaning valley closure, is self-explanatory, "Wehr" is a much less elastic term in German than weir in English, and "River Barrages," is obviously the correct equivalent of the title of Vol. II. In layout this is fundamentally similar to Vol. I, but is much more mathematical, as might be expected in connection with structures which, in addition to being subject to the static stresses occurring in storage dams, are submitted to substantial dynamic stresses as well; they also involve extensive flow studies. The chapters devoted to sluice and control gates include most of the latest additions to this class of equipment.

Among the fair number of books published on dams and barrages in recent years, these two first instalments of Professor Press's work certainly form a most valuable and up-to-date contribution to this class of technical literature. Intended as textbooks for German technical colleges, they are written in a clear and concise manner, and will be welcomed by English readers interested in the subject and commanding a fair knowledge of German.

The work will be completed by a third volume devoted to hydro-electric power plants and their equipment.

Bhagirath. Published by the Information Branch, Central Water and Power Commission, Government of India. Annual subscription Rs. 3.

India is faced with the population increment of 12,700 souls per diem and her Government is rightly giving every attention to schemes for irrigating land and providing power. The purpose of the present journal, which is to be published monthly, is to make the necessity for these schemes apparent to as wide a public as possible and to give authentic information on new schemes as they take their place in an ordered sequence of development.

The name "Bhagirath" has been appropriately chosen for the journal because it was this legendary figure who is credited with having laboured so selflessly to cause the Ganga to flow its primaeval and fruitful course through the plains of India and thus symbolises the immense task which lies ahead of the people of India in extending the use of water for power and agricultural development. The first issue, published in June this year, contains an introductory message from M. G. L. Nanda, Union Minister of Irrigation and Power and a number of articles concerned with the Bhakna-Nangal project, power development in the Punjab. The desilting of dams and so on. The editor is Dr. R. S. Rangappa, M.Ss., Ph.D. A.I.I.Sc.

A Swedish Metal Industry. A most beautifully produced bound brochure has been published in English by A. S. Svenska Metallverken giving an intimate picture of the work and life of Scandinavia's largest concern producing non-ferrous metals and their products. The company has factories at Väsby, Västerås, Skultuna, Finspong and Granefors, in addition to central offices in Stockholm. Three of the plants produce semi-finished products such as sheet and strip, wire and cable, tubes, bars, rods and sections, and aluminium foil, the others producing cooking utensils, large containers, storage tanks, and other manufactured articles. These activities are admirably portrayed by the many illustrations, some in colour, which form the chief feature of this most interesting publication.

Fig. 12. The dam, substation building, and switchyard

The Salamonde Hydro-Electric Scheme

Salamonde constitutes the second stage in the development of the Cavado and Rabagao rivers, one of the most important hydro-electric developments in Portugal. The ultimate scheme will have an installed capacity of 260 MVA and its output will equal the whole thermal and hydro output in Portugal for 1950.

By L. H. GOMES FERNANDES
CHIEF ENGINEER OF HIDRO ELECTRICA DO CAVADO

PART TWO

THE water passes from the reservoir to the turbine penstocks through a pressure tunnel cut through the rock in a direction to give the shortest length while not passing below the dam too near to its foundation. This tunnel has a total length of 128 m. and consists of two separate sections. The first has a slope of 10 per cent., a length of 41·3 m. and a circular cross-section 4·1 m. diameter. The second part is much steeper, with a slope of 85 per cent.; its length is 86·7 m. and it has two circular cross sections of 4·1 and 3·3 m. diameter joined together by a smooth transition.

The granite through which the gallery passes is of excellent quality and required only the following lining: Where the water pressure is less than 90 m. head, a simple concrete lining not less than 25 cm. thick is grouted to the rock; a diameter of 4·1 m. was adopted for this section. Where the water pressure exceeds 9 kg. per sq. cm., a metal lining 15 mm. thick is placed within the concrete annulus. Since the lining had to resist possible external pressures, it was re-

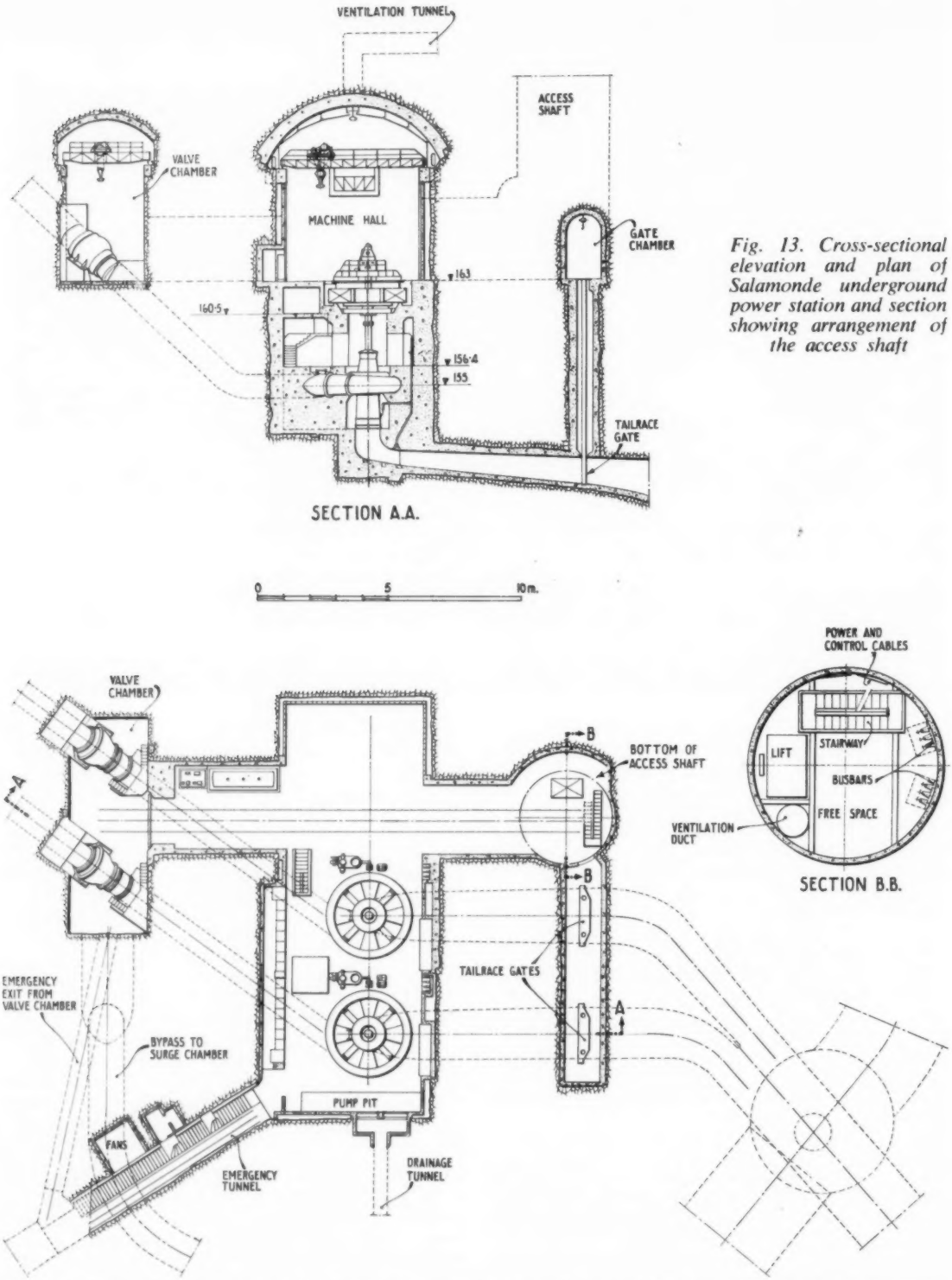

Fig. 13. Cross-sectional elevation and plan of Salamonde underground power station and section showing arrangement of the access shaft

inforced externally by rings of 100 × 200 × 12 mm. rolled angle section spaced 90 cm. apart. After this section, which has a diameter of 3·3 m., was concreted, grout was injected to ensure perfect contact throughout its length between the metal lining and the concrete.

The water velocities in the two parts of the gallery are 3·18 and 4·92 m. per sec. respectively for a maximum design flow of 42 cu. m. per sec. The flow

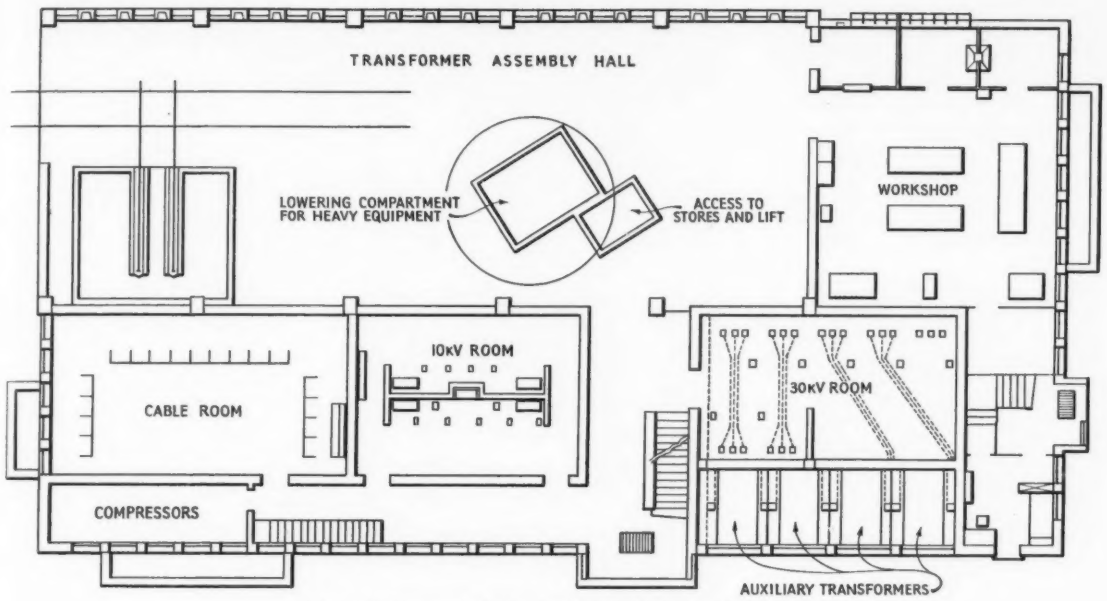

Fig. 14. Layout of the surface substation building

through the gallery is controlled at its entrance by a 3·20 × 5 m. Stoney gate operated by an oil servomotor from the top of the intake tower.

In order to prevent solids from passing into the tunnel and fouling the turbines, thus possibly prejudicing the safety of the machines, a fixed concrete trashrack with 25 cm. spacing between the bars is arranged at the water intake. Additional protection is afforded by a mobile metal rack upstream of the gate, size 3·80 × 5·80 m., the bars of which are set at 40 mm. centres; it can be lifted by winches mounted at the top of the tower.

The tower itself is constructed of concrete; it has a circular cross section and is approximately 50 m. high. It is surrounded by a chamber containing the gate servomotor and the winch for the rack. A footbridge of 14 m. span joins it to the crown of the dam and a platform is arranged inside it at elevation 273·4 m. to permit inspection and repairs to be carried out to the gate and the metal rack. The tower also contains a duct to supply air to the pressure gallery.

The gate-lifting mechanism, like that of the bottom-outlet gate, can be operated when the hydraulic pressures are not balanced; it is fitted with an automatic device to compensate for any slight lowering of the gate due to oil leakage from the piping. It can be controlled either locally or remotely from the station control room; in addition there is a control point in the underground power station from which the gate can be lowered in an emergency.

The pressure gallery bifurcates at its end to form the two turbine penstocks in which are set the turbine inlet valves housed in a separate chamber.

The turbine penstocks have a diameter of 2 m. upstream of this valve and 1·8 m. downstream of it. They have a steel lining similar to that of the final part of the pressure gallery, 13 and 14 mm. thick in the two sections, the space between it and the rock being filled with concrete. The lining is reinforced against possible external pressures by angle-iron rings 100 × 200 × 10 mm. spaced 1·35 m. apart in the larger section and 2 m. apart downstream of the valves. Close to the valve within the chamber itself the penstocks have no concrete covering and consist of steel plate 25 mm. thick.

At the maximum design flow of 42 cu. m. per sec. the water velocity in the large and small sections of the penstocks are 6·70 and 8·35 m. per sec.

The intake works described above were designed on the basis that the maximum pressure surge caused by the valves or the turbine governors does not exceed 25 per cent. of the static head. The head lost when passing the maximum design flow of 42 cu. m. per sec. was calculated to be 4·1 m.

Tailrace

After passing through the turbines the water is returned to the valley of the Cavado by a tailrace tunnel operating under a slight head. It has a standard horseshoe section of 29·9 sq. m. area and is 1,860 m. long; it passes through granite of excellent quality and did not require any lining except for some short sections which together slightly exceed 100 m. in length.

The concrete weir at the end of the tailrace forms a circular arc 22 m. long with its sill at elevation 153 m. It will operate continuously until the completion of the Canicada reservoir, the third stage of the development, which is at present under construction; thereafter it will only function when the level in that reservoir falls below 153 m.

Surge Chamber

A surge chamber communicates with the commencement of the tailrace tunnel. It lies immediately downstream of the station but separated from it by a sufficient thickness of rock to ensure that no water seeps from it into the power station.

A throttle consisting of a circular orifice 2·90 m. diameter is arranged at the bottom of the surge

chamber, and two expansion chambers are used, a lower one of 320 sq. m. horizontal section and 8 m. average height with its invert at an average elevation of 147·90 m., connected by a vertical shaft of 80 sq. m. circular cross section to an upper chamber 6·7 m. high which has a horizontal area of 420 sq. m. and its invert at an average elevation of 164·40 m.

An investigation was carried out into the stability of the hydraulic system, including this surge chamber, using the following as the worst possible conditions:—

(a) Full closure from maximum discharge in 80 seconds with the highest static water level (163 m.), the roughness of the tailrace tunnel corresponding to $M=22$ in the Strickler formula;

(b) Instantaneous opening from the fully closed position to maximum flow, with the lowest static water level (153 m.) and the tailrace roughness corresponding to $M=35$ in the same formula.

The calculations show that the oscillations of the water level in the surge chamber reach a maximum height of 168 m. and a minimum of 149·2 m.; this last value indicates that no air will enter the tailrace tunnel since this water level is still more than 2 m. above the surge tank throat.

In view of the excellent quality of the granite in which the surge chamber has been excavated, the lining originally provided for was omitted, as also was that of the tailrace tunnel.

Air is supplied to the surge chamber through a tunnel which starts at the top of the upper chamber and connects at the power station access shaft to a metal pipe which runs above through the shaft, passes through the substation building and is open to atmosphere at the roof of the transformer assembly hall.

The loss of head along the tailrace when passing the maximum design flow of 42 cu. m. per sec. is 3·90 m. Under the same conditions the total loss of head through headrace and tailrace is 8 m., representing 6·8 per cent. of the maximum total head of 127 m.

Fig. 15. Placing the concrete for the turbine foundations in the underground power house. The mouth of the inclined access tunnel can be seen in the right background and those of the tunnels to the access shaft and valve chamber in the left and right foreground

Machine Hall

As already mentioned, the outstanding feature of the scheme is the underground power station (Fig. 13) which is joined to the substation building at the surface (elevation 284 m.) by a vertical shaft 121 m. high. This arrangement was chosen for economic reasons in view of the shorter headrace subject to high pressures, although it involved a much longer tailrace, which, however, operates under much lower pressure.

Considerations of the same nature have led to the installation underground of the two main sets and all the equipment and apparatus essential for their operation, while the remainder is arranged on the surface in the substation building and the adjoining yard.

The actual position and orientation of the power station were based on the following considerations:—

(a) The headrace exposed to high pressures should be as short as possible, and the turbine penstocks should enter the station in the most suitable manner;

(b) The direction of the tailrace should be convenient for the plant layout adopted;

(c) Both the power station and its access shaft should be located downstream of the dam so that they are protected by the grouting curtain;

(d) The access shaft and the substation building on the surface should be in a suitable position.

The machine hall of the power station has a floor area of 327 sq. m. and a maximum height of 13·6 m., the floor being at elevation 163 m. It is served by a travelling crane of 55-ton capacity and contains the alternators which are partly sunk below floor level, the turbine governors, the drainage pumps, and in open wall recesses the control boards for the alternators, turbines and the auxiliary services of the underground power station.

The turbine floor is located at elevation 156·4 m., below the main hall, and is reached by a stairway. The crane hook can be lowered through an opening in the floor between the two alternators in order to

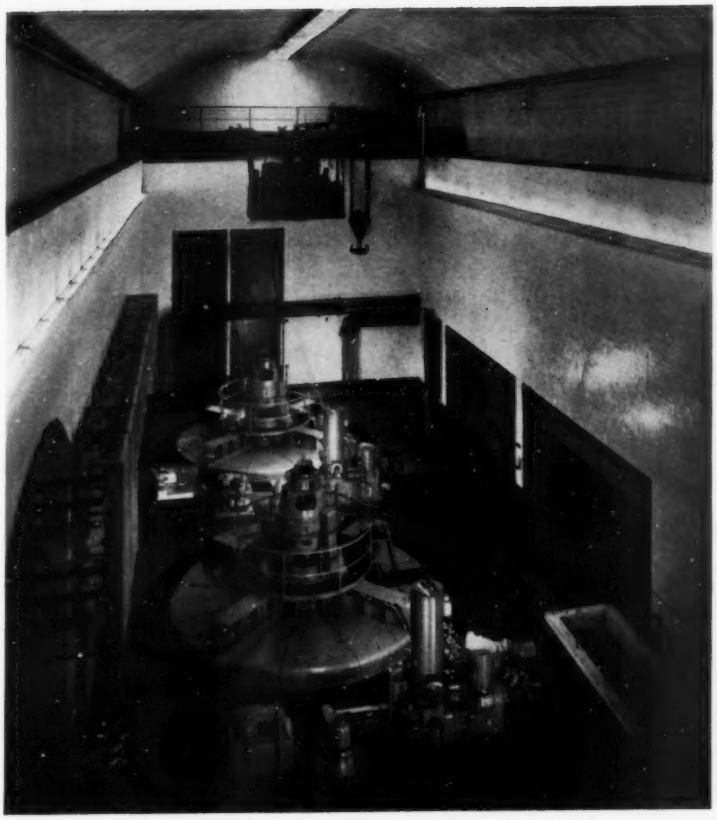

Fig. 16. The completed machine hall. The grating in the floor protects the opening for lifting out the turbine runners

remove the turbine runners for repair, when necessary.

Large tunnels lead from opposite walls of the machine hall to the bottom of the access shaft and to the valve chamber. A bogie runs on rails through these tunnels and across the hall in order to allow heavy equipment to be moved. The space in the machine hall beyond this track served as assembly area during the installation of the plant and will in future be used for any repairs that have to be carried out.

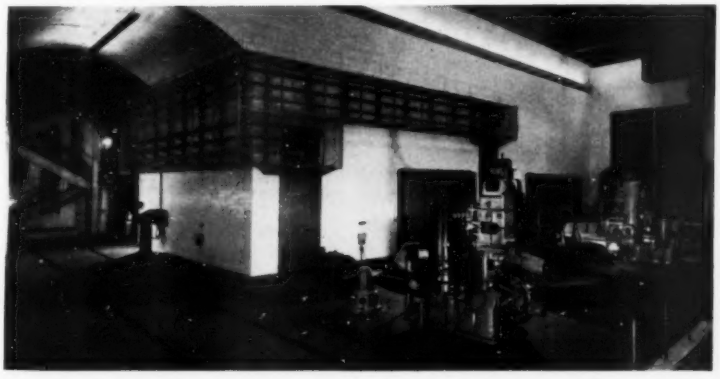

Fig. 17. Part of the machine hall showing the entry to the access shaft

The construction of the machine hall of the station and its two extensions, the turbine valve and tailrace gate chambers, together with all secondary tunnels, involved excavating a volume of some 14,700 cu. m., while the maximum height reaches 31·5 m. in the machine hall. All work was carried out from an adit starting at the surface on the left-hand bank of the river at elevation 224 m. and sloping down at 69 per cent., reaching the machine hall at one of its corners at elevation 163 m. This construction adit has been retained to serve as an emergency exit from the power station; it contains, at suitable levels and in special chambers, the water tanks for the alternator and turbine-bearing cooling systems, the ventilation equipment for the power station and the sanitary installations.

The machine hall was excavated by raising vertical shafts from the adit into the upper part of the hall up to its full height, the roof being concreted in step with the advance of the excavation.

The power station crane runs on beams suspended by tension bars from the springs of the roof arch (Fig. 15). This arrangement allowed for the concreting and the assembly of the crane to be carried out before the main excavation was completed so that the station crane could be employed during the construction of the station itself.

The machine hall lies in granite of excellent quality and contains only a single geological fault, an almost vertical fissure a few centimetres thick filled with clay, which has made it necessary to make special arrangements at the wall near the access tunnel to the vertical shaft. The cleavage lines of the rock appeared initially to be completely closed but showed a tendency to open slowly, obviously as a result of the disequilibrium of the rock mass produced when the hall was excavated. The vertical rock faces above elevation 163 m. were therefore treated by the following method. Steel bars 16 mm. in diameter were grouted into holes in the rock 1·50 m. deep made with a pneumatic hammer and averaging 1·6 per sq. m.; alternating with these were steel bars 25 mm. diameter grouted into 4 m. deep holes and arranged at a density of 0·65 per sq. m. After these bars had been placed into the holes and grouted in for part of their length, they were loaded in tension and the load maintained while the holes were filled with grout and until the latter had set completely.

The machine hall is surrounded by brick walls, leaving a small space at the rock surface through which any water seeping into the hall can drain away. The walls are covered with tiles on the inside, as are the access tunnels to the bottom of the shaft and to the valve chamber. The floor is covered with a ceramic mosaic.

A false ceiling of bent aluminium sheeting is suspended from the roof and protects the station against any seepage of water from above.

The power station is lit by fluorescent lamps arranged along the top of the arch and along the lower parts of the beams supporting the crane (Fig. 16).

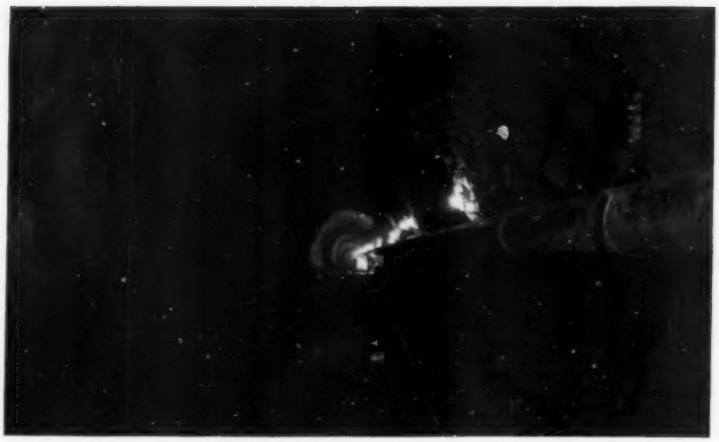

Fig. 18. The tailrace tunnel under construction

Valve and Gate Chambers

The valve chamber has an area of 93 sq. m. and a maximum height of 12·1 m. Like the machine hall it is protected by an arched concrete roof and contains a travelling crane of 30 tons capacity. It houses the two inlet valves to the turbines.

The valves are of the in-line type and are fitted with a double seat. They are self-closing, that is they are shut by the water pressure in the penstock on any failure of the oil pressure which keeps them open. The double-seat arrangement makes it possible to carry out repairs or to replace one of the seats during normal operation and also to repair the operating mechanism without having to drain the penstock. The oil pressure for operating the valves is supplied by a pumping set arranged in the access tunnel to the chamber.

In view of the good quality of the granite already referred to, no lining whatever was considered necessary in this chamber, the rock surface being left freely visible.

In order to prevent any flooding of the power station in the event of damage to the valves or the penstock sections on their upstream side, the valve chamber is separated from the machine hall by a watertight door, and any flood water is removed through a bypass tunnel running to the surge chamber. The invert of this bypass is at elevation 168·7 m., that is above the maximum height of the water level in the surge chamber.

The emergency exit for personnel consists of a small horizontal tunnel, area 2·9 sq. m., starting from the upper part of the chamber at elevation 173·5 m. and joining the inclined tunnel which runs to the surface.

Any water seeping into the valve chamber drains to the sump in one of the corners of the machine hall through a 15 cm. diameter pipe arranged alongside one of the turbine penstocks.

The chamber housing the tailrace gates is concrete lined, 13·4 sq. m. in cross-section and 17 m. long, with its floor at elevation 163 m. It is reached from the bottom of the access shaft to the power station.

The steel gates $4{\cdot}20 \times 2{\cdot}18$ m. in area have been inserted in the turbine tailrace so that the machines can be unwatered for inspection and repair. This becomes necessary because the water level downstream of the power station, even with the sets shut down, is above the elevation of the turbines. For the same reason the gate shafts in the floor of the chamber have to be closed by watertight plugs.

The gates are operated after the pressures have been balanced, using a differential hoist which runs on a monorail suspended from the roof of the chamber.

Drainage

Any water seeping into the machine hall and its connected chambers, as well as into the access shaft and the inclined tunnel to the surface, is taken through pipes to a sump at one end of the machine hall the floor of which lies below the lowest point of the underground station. The same sump also takes any leakage through the seals of the tailrace gates when the turbines are unwatered.

From this sump the water is pumped to the surge chamber through a tunnel which starts at the end of the machine hall close to the pumps at elevation 168 m. and runs to the bypass tunnel joining the valve chamber to the surge chamber.

The cooling water for the alternators and the turbine bearings is discharged by gravity through the same tunnel; the corresponding feed tanks in the inclined tunnel have therefore been arranged at a suitable elevation (water inlets at elevations 182·8 m. and 182·3 m.). These tanks are normally supplied through pipes from the draught tubes with water which has already passed through the turbines; when the turbines are stopped, however, they may be fed through another pipe connected to the penstocks upstream of the inlet valves. The tanks contain a float valve which controls the admission of the water.

The drainage pumps are of the vertical-shaft type with axial suction pipes; their motors are mounted on the power station floor. The following sizes have been installed:—

1 pump discharging 8 litres per sec. (5 h.p. motor);
1 pump discharging 28 litres per sec. (13·5 h.p. motor);
3 pumps discharging 50 litres per sec. each (22 h.p. motors).

They all operate against 20 m. static head. The first pump discharges the small permanent seepage whereas the second is brought into operation to unwater the turbines and the corresponding draught tubes. The three large pumps were installed to deal with any

emergency, such as heavy leakage through the seals of the tailrace gates.

Ventilation and Access

The ventilation of the power station is ensured by natural draught through the access shaft. Two auxiliary fans are installed in a chamber along the inclined shaft, rated at 135 and 205 cu. m. per min. respectively; as already mentioned, their controls are mounted adjacent to the alternator and turbine control boards in the machine hall.

A small tunnel runs from the top of the machine-hall roof to the access shaft and removes stale air which collects in the upper part of the chamber.

The air supplied by the fans can be heated by electrical resistances arranged in the intake duct the output of which can be set at 15, 22·5 and 37·5 kW.

The power station is normally reached by the vertical shaft which starts in the transformer assembly hall near the substation (Fig. 14) at elevation 284 m. and runs down to elevation 163 m. As already mentioned, the inclined tunnel which served as adit during construction is being maintained solely as an emergency exit for the personnel.

The concrete-lined shaft (Fig. 19) has a diameter of 7 m. and contains the busbars from the alternators to the main transformers which are protected by wire-mesh panels, the control and power cables connecting the power station to the substation building, a service stairway in reinforced concrete with landings every 1·75 m., a 1,500 kg. lift for both personnel and goods, and a metal duct 960 mm. diameter which provides ventilation for the surge chamber. The clear space, measuring 3×4 m. which remains is used for raising and lowering the heavy equipment of the power equipment of the power station by means of the travelling crane in the transformer assembly hall.

Fig. 19. Looking down the access shaft, showing the free space for lowering heavy equipment. The stairway is seen at top centre, the busbar and cable inspection platforms on the right, the lift shaft at left centre, and the air duct to the surge chamber at bottom left

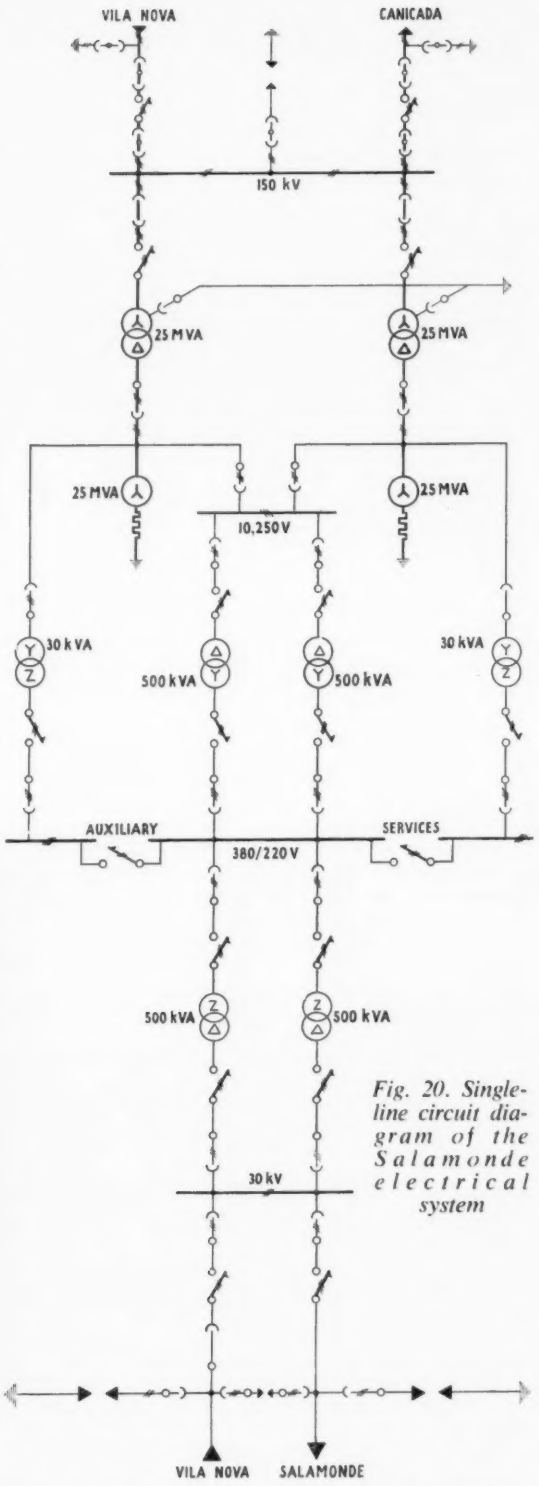

Fig. 20. Single-line circuit diagram of the Salamonde electrical system

The reinforced-concrete elements forming the structure of the shaft, namely the inspection and main-

tenance platforms for the busbars and cables, the stairway itself, the beams supporting the platforms and stairs, and the lift guides, were prefabricated on the surface and placed in position as soon as the shaft lining had been completed.

Substation

Part of the substation equipment is arranged inside the building and the remainder inside a yard at elevation 284 m. (Fig. 18).

The building consists of two floors and a basement. In the basement are the incoming busbars and cables and the outgoing connections to the transformer primaries, the battery room, and the store. On the ground floor are the 10 and 30 kV cable rooms, a compressor room, a workshop, and the cells for the auxiliary transformers the doors of which open into the yard. The first floor contains a room for the auxiliary services, the control room and the technical and administrative offices.

The transformer assembly hall lies next to the substation building; it forms with it a structural unit and has direct access from it. It has a floor area of 350 sq. m. and is served by a 40 ton travelling crane which is also used for the access shaft to the power station. The floor of this hall lies at elevation 284 m. and contains two rectangular openings, one for passing equipment down the shaft to the power station and the other for lowering goods by means of the crane to the store in the substation basement and to the access-shaft lift.

Provision has been made for erecting a 125 kVA diesel generating set in the substation building, which is to be delivered shortly. It will be used mainly for driving the drainage pumps in the power station when the main equipment is out of commission and also if the external 30 kV supply should for any reason be interrupted. The set will also supply power to operate the gates at the water intake and on the spillway in the same circumstances.

The two main step-up transformers are erected outdoors. Pneumatically-operated isolators and compressed-air switchgear connect them to the busbars and similar equipment controls the outgoing 150 kV transmission line.

A three-phase set of lightning conductors is connected to the busbars and acts as a system of guard wires, protecting the substation against voltage surges.

The transmission line, the busbars themselves, and the conductors joining the latter to the main transformers are carried on a metal structure consisting of portal frames. The switchgear, the isolators, and the voltage and current transformers are mounted on concrete pedestal.

The low-tension cables and the compressed-air lines run in covered ducts arranged below the surface of the switchyard.

Electrical and Mechanical Equipment

The data of the main electrical and mechanical machinery in the power station and substation are given below:—

Turbines: Two vertical-shaft Francis turbines, maximum output 29,600 h.p. under 120 m. net head and with a 21 cu. m. per sec. discharge, running at 428 r.p.m.

Alternators: Two three-phase machines with closed-circuit ventilation,

continuous rating ..... 25,000 kVA
power factor ..... 0·85
output at zero power factor leading...16,000 kVA
rated voltage ..... 10,250 V
PD^2 ..... 350,000 kg. m.^{2}
frequency ..... 50 c/sec.

Transformers: Two naturally cooled three-phase transformers without fans, connected delta-star with neutral earthed and rated at 25,000 kVA with a voltage ratio of 10·25/160 kV $\pm$ 5 per cent.

Auxiliaries:

Two 30 kVA transformers 10,250/380 V
Two 300 kVA transformers 10,250/380 V
Two 500 kVA transformers 30,000/380 V

Temporary River Diversion

Two cofferdams and a diversion tunnel through the right-hand bank had to be constructed to give access to the river bed at the dam site for preparing the foundations and placing the concrete. The diversion works were designed not for the highest flood predicted, which would have resulted in excessive cost, but for a discharge of only some 500 cu. m. per sec. At larger flows the upstream cofferdam was overtopped and the water passed through two openings in the dam on either side of the bottom-outlet conduit. These openings were closed under the protection of the upstream cofferdam before the plug closing the diversion tunnel was constructed.

The main data of the diversion works were as follows:—

Upstream cofferdam: Concrete arch dam of constant radius and thickness, having the following dimensions:

Outside radius ... 35 m.
Crest elevation ... 218 m.
Maximum height ... 10 m. approx.
Thickness ... ... 1 m.

It contained a bottom outlet fitted with a steel gate.

Diversion Tunnel: Unlined, horseshoe section of 50 sq. m. area, approximately 100 m. long. Its entry was formed by a concrete structure with its sill at elevation 210 m.; it contained two independent passes which were closed during the construction of the tunnel plug, the river discharge passing through the bottom outlet of the dam.

Downstream Cofferdam: Rock-fill dam built up of large wire baskets filled with rock, with a central grouted core made from excavated material; crest at elevation 212 m.

The concrete plug in the diversion tunnel lies below and slightly upstream of the main dam. It is connected to the main sealing curtain by a fan-shaped series of grouting holes, 13 in number and totalling 228·4 m., which were sunk using a percussion drill and which absorbed 5·3 tons of cement and 17·4 cu. m. of activated clay.

Switchgear. Cooke & Ferguson Limited, Manchester, have forwarded three further catalogue sections dealing with switchgear of their manufacture. One section gives details of oil circuit breaker Type D2, which is A.S.T.A. tested up to 100 MVA at 6·6 kV and 150 MVA at 11 kV. The second refers to UTD-4 metal-clad units, which are of the duplicate-busbar air-insulated vertical-isolation type, rated at 350 MVA at 11 kV. The third gives particulars of Type OE-5 outdoor circuit breakers rated at 1,000 MVA at 33 kV.

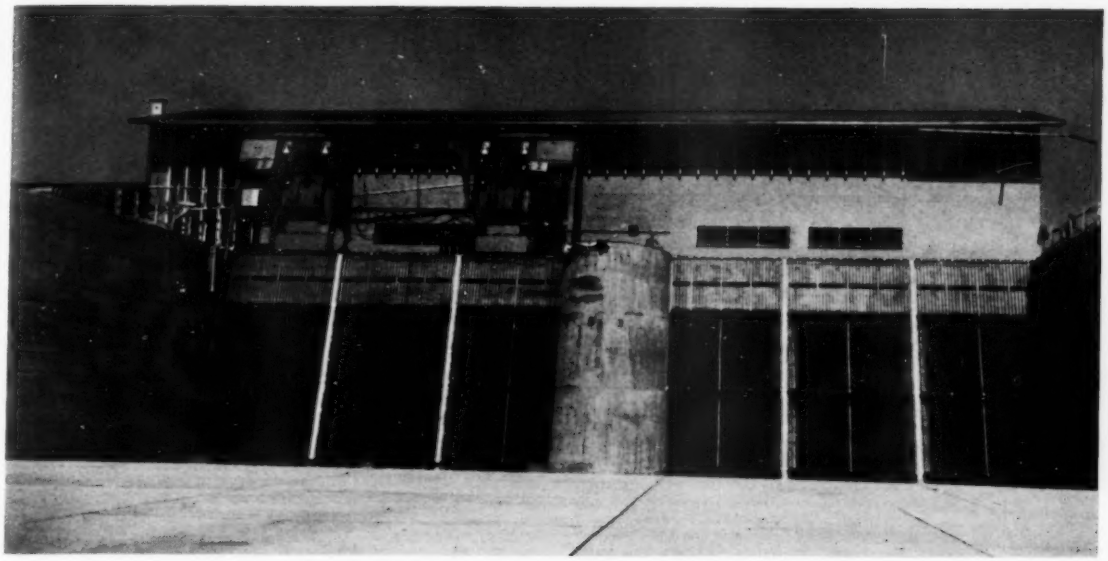

Fig. 1. Turbine intakes of the Wildegg-Brugg station before flooding, showing the two screen-cleaning machines coupled for handling stoplogs

Electrical Shaft Coupling for Stoplog Hoist

The principle of the Selsyn coupling is explained, together with an account of its application to a system of hoists at the intake of the Wildegg-Brugg power station, Switzerland.

By F. JALLA and H. LUTZ

As is well known, a coupling serves to connect two or more pieces of machinery which must run together. Normally this object is attained by a simple mechanical coupling. If the speeds (n_1, n_2) of the parts to be coupled are equal, they can be coupled directly; if, however, n_1 and n_2 are not equal, a transmission gear (e.g. toothed gearing) must be interposed. A coupling can fulfil various functions. First it can serve to transmit the torque from the driving to the driven part, or it can couple two separately driven parts in such a way that synchronism is enforced. In the latter case, only differences in the working torque have to be transmitted.

Certain cases occur in which it is difficult to use an ordinary metal coupling for coupling a driving and a driven component to secure some mechanical end; for example, the distance between the parts to be coupled may be excessive or various obstacles may intervene, or the relative positions may be unfavourable. A mechanical coupling is awkward and expensive in such circumstances, especially when it is considered that, in order to avoid excessive torsion angles with high torques, shafts with relatively large diameters must be used. Here electrical engineering can provide an answer that is both economical and technically sound.

A first solution would be the use of synchronous motors which would operate both the driven components at the same speed, since the speed is necessarily fixed by the supply frequency. Synchronous-reaction motors have been used for this type of drive under certain conditions. The synchronous drive, however, can only be ensured at normal speed and not at starting and stopping; further, it makes only a single fixed speed available; furthermore d.c. excitation is necessary for larger synchronous machines and this entails complications which tend to be costly. The general solution of the problem is much more successful with specially connected induction machines, an arrangement which is called the "electrical coupling" as it behaves exactly like a mechanical coupling.

The electrical coupling consists in principle of two or more slipring induction motors which are electrically connected together. The machines can have equal or unequal loads; the numbers of poles p_1 and p_2 can

be equal ($p_1/p_2=1$) or unequal ($p_1/p_2=n_2/n_1$). The stators of these "coupling" machines, or "Selsyns" (an abbreviation for "self synchronising") are connected to the same three-phase supply. Their rotors are connected together in parallel (with the same phase rotation), and, if required, further series or parallel impedances can be connected in the rotor circuit. This parallel connection of the rotor entails that the coupling machines must produce equal open-circuit voltages on the rotor, since otherwise an undesired equalising current would flow in the rotor circuit. With the shaft stationary no current should flow in the rotors in spite of the stators being excited.

The action of this arrangement is as follows: the well-known relation for an induction motor is:

$$f_2=sf_1$$

where s is the slip, f_1 the stator frequency and f_2 the rotor frequency. Since the stators are connected to the same supply, f_1 is the same for all the coupling machines. The parallel connection of the rotors entails equal rotor frequency, so that in consequence the slip of all the coupling machines must be the same, that is to say, all the rotors must perform exactly the same movements. For example, if one of the rotors is driven in any way by one machine unit, all the other rotors electrically connected with it run together exactly synchronously, and can enforce their speed on another unit to which they are coupled through the electrical coupling.

As an example of the many possible forms of electrical couplings, the so-called "tie coupling" will now be described. It comes into use when two separately driven machines have to run synchronously with each other. Such a coupling is shown diagrammatically in Fig. 2. The two three-phase motors M_A and M_B drive the machinery L_A and L_B. The separate driving power required is supplied for the most part by each motor respectively. Coupling machines S_A and S_B are coupled to each driving motor. The rotors of these coupling machines (Selsyns) are connected in parallel electrically without the insertion of additional impedances. In the case considered the two main motors, as well as the coupling machines, are of identical construction.

The electrical coupling acts in such a way that at any moment the speed n_1 is equal to n_2 independently of whether the two main motors are equally or unequally loaded. With equal loading ($L_A=L_B$) the driving motors automatically run at the same speed, since in the present case they have like characteristics. The rotor voltages of the coupling machines are equal and in phase with each other, so that no equalising current flows in the rotor circuit and no load is transmitted between part A and part B. As soon, however, as the load on part A is more or less than on part B, load is transferred from the part with the lower load to that with the higher, seeing that, by hypothesis, the two parts always have the same speed and, therefore, the main motors necessarily maintain equal loads from the stators. In other words, in one place there is an excess of load and in another a deficit, which must be equalised through the coupling.

The transmission of a torque through the Selsyn machines comes into effect by the fact that, although the rotor voltages are still equal, their relative phase angle is changed, so that an equalising current now flows in the rotor circuit. The phase shifting of the rotor voltages is introduced by a small relative angular displacement of the two rotors, i.e. of the two parts A and B, which corresponds to the elastic twisting of a mechanical shaft. As a mechanical shaft must not be stressed above the torsional elastic limit so has the electrical "shaft" a limit to the torque which can be transmitted, and this is given by the pull-out torque of the Selsyn machines. Since the pull-out torque increases with higher slip, coupling machines are normally designed with slips above unity, viz., from 1 to 2·5, i.e., they run against their own rotating field.

With correctly dimensioned coupling machines and suitable connections the equipment assures satisfactory parallel running with very unequal loads.

Application at Wildegg-Brugg Power Station

The Wildegg-Brugg hydraulic power station, built on the Aare by the Nordostschweizerischen Kraftwerken (NOK), is provided with two Kaplan turbines, each of 23,000 kW capacity and a flow of 175 cu. m. per sec. and a head of 14·6 m., the speed being 115·4 r.p.m. Each set has a separate intake (Fig. 1) which, during an overhaul, can be closed by means of stoplogs (Fig. 3). For this purpose the two screen-cleaning machines co-operate. These machines, supplied by Jonneret Fils Aîné of Geneva, are arranged right-and-left hand fashion and are provided with auxiliary winches which, for lowering and raising the stoplogs, are connected by an electrical coupling. The electrical drive, which was supplied by Schweizerischen Wagons-und Aufzügefabrik A.G., Schlieren, in collaboration with Oerlikon as sub-contractors, has to fulfil two primary conditions.

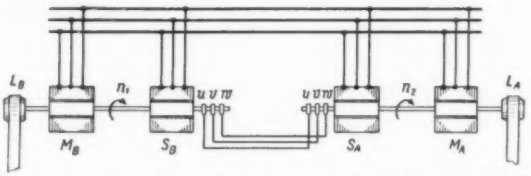

Fig. 2. Basic connections of an electrical coupling

(a) Raising and lowering the logs in a simple and safe way.

(b) Guarantee that the horizontal position of the logs is preserved in all conditions of weather and in spite of any unequal forces due to friction, water, ice or dirt.

The two screen-cleaning machines act entirely independently when cleaning the grids but work in combination when in use for the stoplogs. For this purpose they are coupled mechanically by a connecting beam, so that their distance is accurately maintained. The control circuits of the two sets are connected, partly in series and partly in parallel, by means of an electric cable with plugs. Each grid-cleaning machine has a changeover switch for the control circuit, by which the main winches for cleaning the screens are put out of action during the combined operation of the auxiliary winches. A further cable connects the rotors of the two Selsyn machines, each of which is coupled to the driving motor of the auxiliary winch for the stoplogs. These Selsyn machines form an electrical link which ensures that the winches act exactly parallel to each other and the stoplogs are therefore kept accurately horizontal

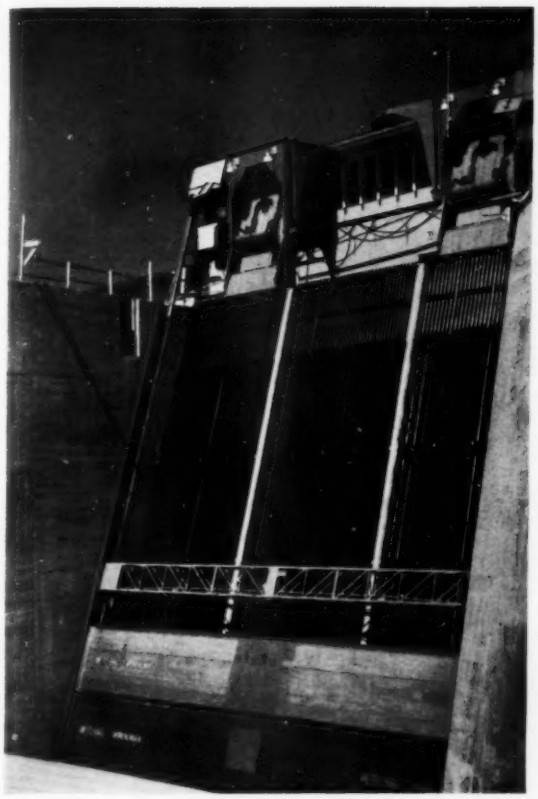

Fig. 3. A closer view of the coupled machines at Wildegg-Brugg, showing two stoplogs in position

during the whole of the operation. A condition is thus reached in which the logs cannot jam in their slots during raising or lowering.

Fig. 3 shows the mechanically and electrically coupled machines for positioning the stoplogs, which can now be operated from a single control point. The switchboard on the one cleaning machine is provided with two control switches and two measuring instruments. One of these shows the height of the stoplogs in metres and centimetres, while the other gives any difference in height that may occur during operations between the two ends of the beam. Such a difference in height can be corrected at rest by putting one winch out of action by a lever switch and interrupting the electrical coupling, while with the second operating switch the other winch is controlled independently.

The stoplogs themselves have the following characteristics:—

Weight of log element	12·5 tons
Weight of log grip	3·2 tons
Total length	60 ft.
Height	8 ft.
Number of logs	7

The logs are raised or lowered at a speed of about 3 ft. per min. A diagram of the motor torque required during the removal of the three highest logs is shown in Fig. 4. The first load peaks occurring correspond to the breaking free of the beams; generator action occurs when lowering so that the load must be braked.

An arrangement with two independent induction motors would not have been able to fulfil the condition of synchronism, and a mechanical coupling between the two otherwise separate grid-cleaning machines could only have been provided with great inconvenience and considerable cost.

The actual winch motors (Fig. 5) have double-cage rotors, and the intermittent rating of each is 10 h.p. at 1,380 r.p.m. The slipring Selsyns (Fig. 6) can be intermittently loaded as regards heating up to a torque of 2·5 kg. m., which for a normal three-phase machine would correspond to a load of about 5 h.p. at about 1,500 r.p.m. They run with a slip between 1 and 2, and within this range are capable of equalising in-

(Continued on page 464)

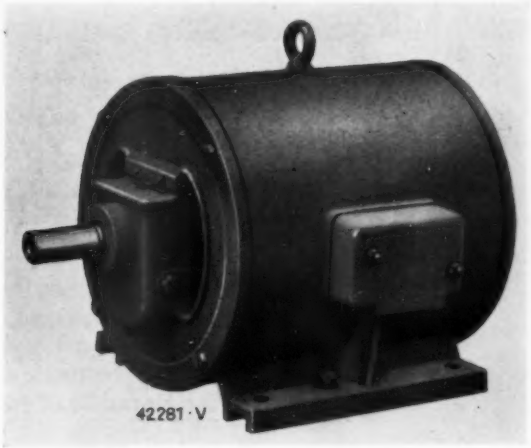

Fig. 5. Oerlikon double-cage induction motor used as main motor for an electrical coupling

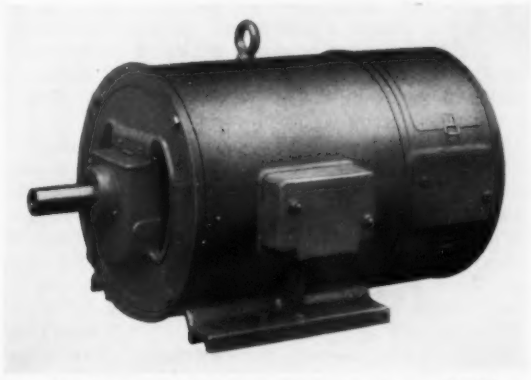

Fig. 6. Selsyn machines, consisting of an Oerlikon three-phase slipring motor

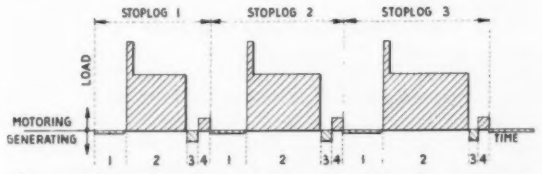

Fig. 4. Torque-time diagram of the winch motors when removing the top three stoplogs: 1, lowering the grab; 2, lifting the stoplog; 3, parking the stoplog; 4, raising the grab

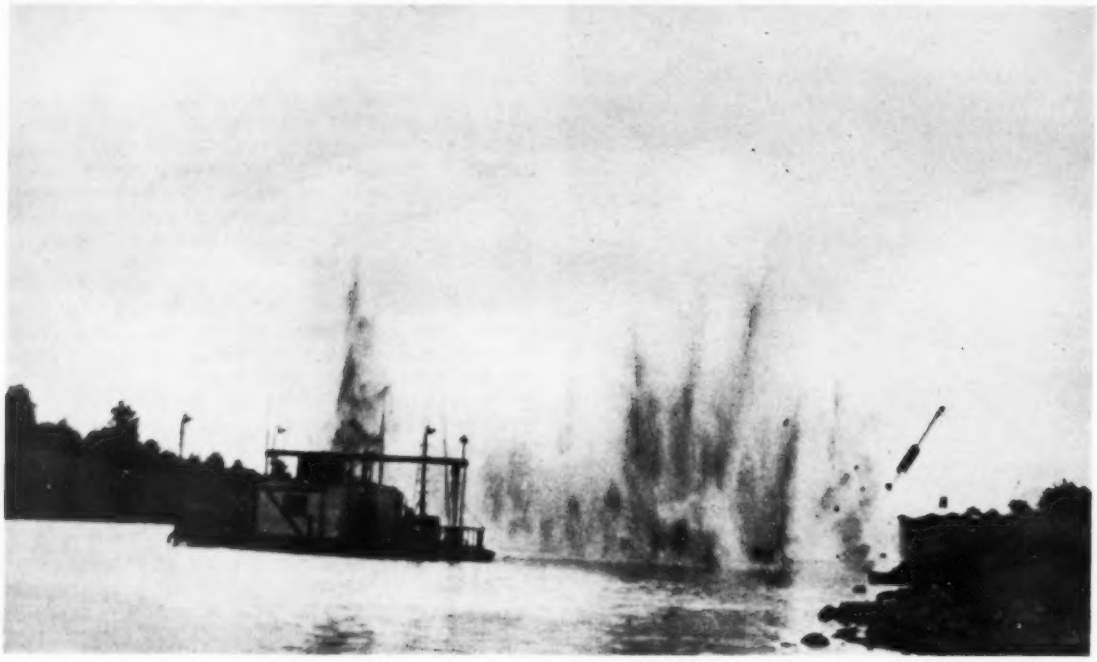

Fig. 1. Blasting boulder clay in the Erne River, Northern Ireland

Deepening a River Bed

Peter Kavanagh describes the operation of deepening the bed of the River Erne between Lower Lough Erne and Belleek in Northern Ireland. This work is being carried out so that maximum use can be made of the Cliff and Cathaleen's Falls stations in the Republic of Ireland, described in this journal in 1953, and represents the final stage of the Erne development.

THE final stage has now been reached in the hydro-electric development of the River Erne, Ireland's second largest river. When completed in about the year 1956 nearly half of the electricity needs of the Republic of Ireland will be supplied in a normal year by water power.

The hydro-electric development of the Erne posed not merely a problem in engineering but also a more serious problem in diplomacy, because the river, for most of its course, flows through Northern Ireland. Without co-operation and goodwill from the Government of Northern Ireland the project could not have been carried out successfully. In fact, the two large lakes, with areas of approximately 14½ sq. miles and 42½ sq. miles, which form the storage basin for the power stations, are completely in Northern Ireland. The power stations themselves, of course, are in the Republic—situated on the river at Cathaleen's Falls and at Cliff. Cathaleen's Falls is one mile up-river from the Ballyshannon estuary, and Cliff is 4½ miles. The estuary is on the Atlantic Ocean in the extreme north-west of the Republic. The construction of both of these power stations and of the 900-acre storage basin in between has already been described in WATER POWER,* and in the articles then published the intention to proceed with the present work was foreshadowed.

Only one further problem remained to be solved before it could be claimed that this hydro-electric project was satisfactorily completed: the shallow boulder-strewn channel between the outlet of the Lower Lough and Belleek, about 3½ miles long, needed to be deepened if maximum use were to be made of the Lower Lough as a storage basin. It would further add to the effective control of the water if the shallow 11½-mile channel between the two

* In the issues of July, August, September and October 1953.

Loughs were deepened and a controlling sluice-gate barrage erected at that point.

The difficulty here, of course, was that the Government of the Republic could not undertake work in Northern Ireland, however important it might consider that work to be. Happily the Government of Northern Ireland expressed its willingness to co-operate, and an agreement between the two interested parties—the Ministry of Finance for Northern Ireland and the Electricity Supply Board for the Republic of Ireland—was signed in 1950, under which the Ministry of Finance of Northern Ireland promised to execute the job under certain specified conditions.

It was agreed, for instance, that the level of the Upper Lough should never be allowed to fall below 150 ft. O.D., nor should it ever rise above 155 ft. O.D., and thus cause flooding of valuable land. Uncontrolled, it often rose to 158 ft. O.D. To this end it was agreed to construct a barrage with sluices between the two Loughs (at Portora, near Enniskillen) with a crest level when closed of 150 ft. O.D., a sill level of 136 ft. O.D., and a total clear water width of 172 ft. The construction of this barrage, however, was of secondary consideration from the point of view of hydro-electric development. What really was of major importance was that the Ministry of Finance for Northern Ireland agreed to undertake the job of deepening the channel between the old sluice gates at Belleek (just above Cliff power station) and the outlet of the Lower Lough, about 3½ miles up the river at Rosscor.

The contract, which was given to the Cementation Co. Ltd., who were also the civil-engineering contractors for the construction of the dams and power stations for the Erne development, called for the deepening and widening of the channel from its outfall at Lower Lough Erne to Belleek sluice gates, a distance of nearly four miles, to such effect that the improved channel would have a capacity of not less than 311 cusecs with the water level of the Lower Lough at 152 ft. O.D. and the water level at Cliff at 143 ft. O.D. The old sluice gates at Belleek were to be removed and the water in the Lower Lough controlled from the sluice gates at Cliff power station. The maximum level set for the Lower Lough was 152 ft. O.D. and the minimum level 147 ft. O.D. The insistence on 147 ft. O.D. as a minimum level was mainly to ensure an adequate stretch of water for the Royal Air Force seaplane base on the Lower Lough at Castle Archdale.

A number of proposals were put forward for the most convenient method of deepening the channel, so that it could take the necessary flow of 311 cusecs. One proposal was to deepen the channel on an average of 2 ft., having a bed width of 240 ft. and a grade from 137 ft. O.D. at Belleek to 138 ft. O.D. at the Lough end. This proposal was set aside as uneconomic because it would cost more to drill this type of shallow but wide channel than it would to drill a deep channel of narrower dimensions.

Another proposal was to excavate a pilot channel on one side of the river about 50 ft. wide at an invert level of, say, 130 ft. O.D. by means of floating plant, and to dump the spoil from the excavation in the middle of the river to form a central cofferdam, behind which a second and larger channel could be

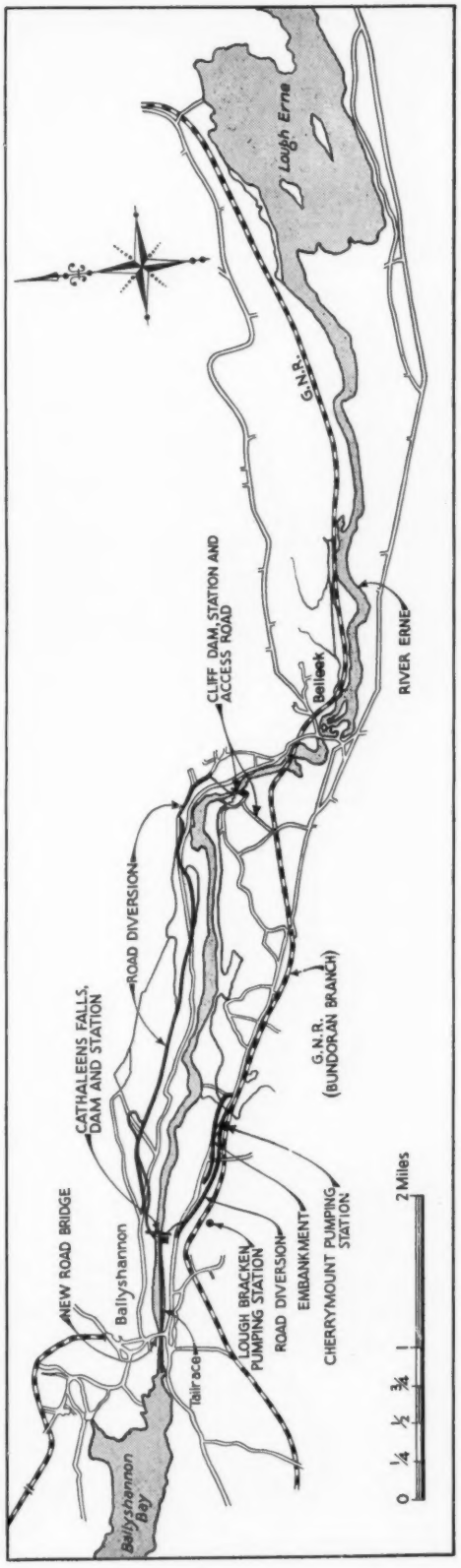

Fig. 2. Map of the Erne River development. The river channel being deepened is seen to the right

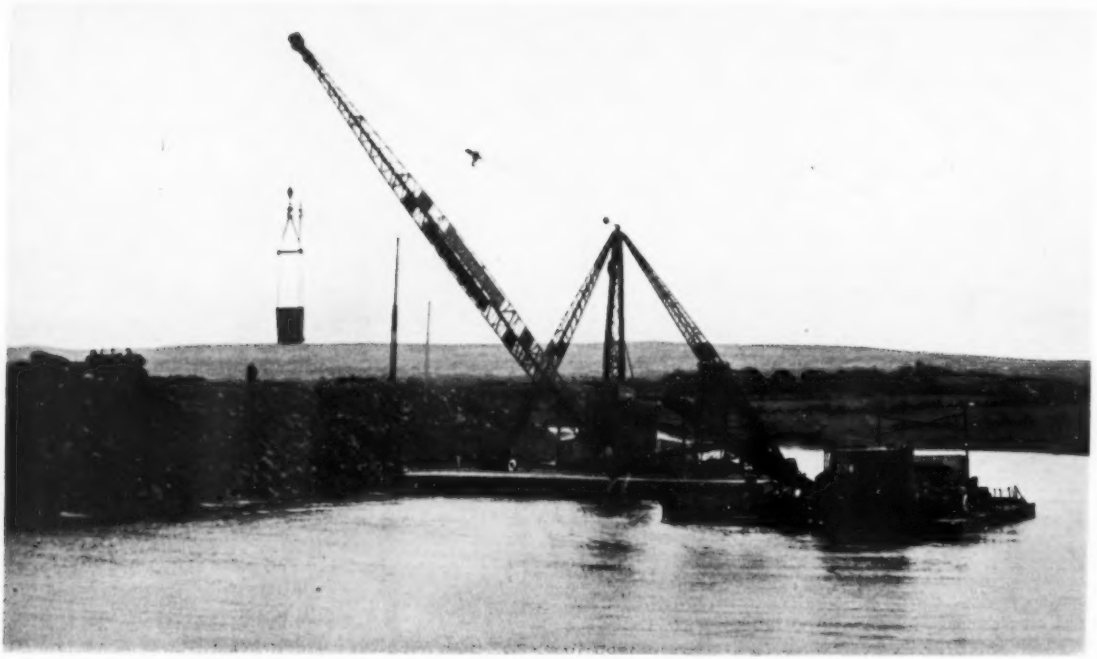

Fig. 3. 37 B excavator and 10-ton floating derrick in operation

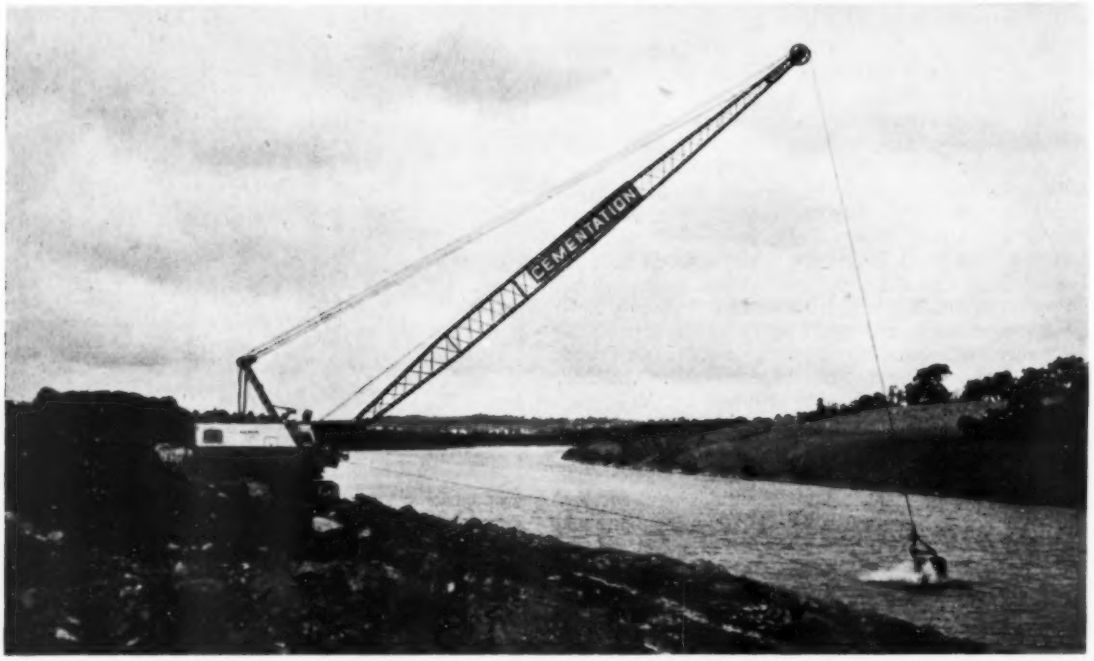

Fig. 4. The Marion 111 M at work on the deepening

excavated in the dry. This proposal also was abandoned at an early stage for economic reasons. There was little doubt that it would be possible to construct a permanent and water-tight cofferdam with the excavated material, but it would prove altogether too expensive to be economic.

The plan adopted, and the one now being carried out by the Cementation Co. Ltd., is the digging of a channel with an average width of 120 ft. and an invert level at Belleek (the power station end) of 133 ft. O.D. The average depth of the face of the underwater excavation is between eight and nine feet.

Later a shallow channel will be dredged along the northern bank to add to the waterway. The invert level at the Lough outlet will be 134 ft. O.D. It is estimated that 356,000 cu. yards of boulder clay and 430,000 cu. yards of carboniferous limestone will have to be excavated before the job is completed.

Work commenced in November 1952 : camps were erected and excavating and other machinery ordered. Pontoons for the floating derricks and for the drill barges were fabricated in Belfast by Harland & Wolff Ltd., and the sections were transported to Belleek and Rosscor, where they were assembled and launched into the river. Erection of a temporary barrage at Rosscor to control, within certain limits, the flow of water in the channel during the excavation was completed in September 1953; this structure will be demolished when the contract is completed. Work on the excavation of the main channel began in June 1953.

There are three drill barges and three excavating units. The drill barges are made of steel, and each of them is moored by four $\frac{5}{8}$ in. diameter wire ropes operated by two double-drum winches driven by compressed air. Two of the excavating units are identical except that one uses a 37 RB Ruston Bucyrus diesel-driven shovel, whereas the second uses a 43 RB Ruston Bucyrus. Both have specially designed dipper arms, the 37 RB being able to reach a depth of 16 ft., whereas the 43 RB can dig to 18 ft. below water level. The excavators sit on steel pontoons which are moored by four $1\frac{1}{8}$ in. diameter wire ropes anchored to concrete deadmen spaced at intervals along the banks. Moored alongside each excavator pontoon is a muck barge in which sit four buckets of 4 cu. yards capacity. And alongside the muck barge and mounted on a steel pontoon is a derrick crane with a 120 ft. jib and a capacity of 10 tons at 90 ft. radius. The excavator, the muck barge and the derrick constitute a unit.

The third excavating unit is a Marion 111 M dragline excavator with 110 ft. jib and a 3 cu. yard bucket. This unit is normally land-based, though occasionally it operates from a self-made island in the channel.

The spoil dumps on the banks are levelled or rehandled by T.D. 18 A International Harvester bulldozers or by $\frac{5}{8}$ cu. yard capacity Ruston Bucyrus draglines.

The sequence of the complete operation is simple enough. The drill barges, generally working downstream, take half of the channel width as an operational face. When drilling rock, holes are bored at 5 ft. centres across the face of the cut. Five to ten pounds of gelignite is put in each hole with Cordtex fuse attached. Eight rows of holes are bored and similarly loaded before firing. An attempt to use the same method on very hard patches of boulder clay, placing the holes at 10 ft. centres, has been successful.

Following the drill barges come the excavating units. The dipper bucket digs the spoil, fills it into one of the buckets on the muck barge, the bucket then being picked up by the derrick and the spoil dumped along the river bank.

The Marion 111 M dragline excavator, as has been explained, operates usually from the bank, and dumps the spoil well behind it. The operation goes on non-stop, night and day. Huge quantities of clay and rock already line the banks, and more is being continuously added. To sharpen the pace still further, two-way communication by radio-telephone is installed on all operating units.

Before work was started on deepening the channel, Lower Lough Erne would have to reach a level of 154 ft. 6 in. O.D. in order to produce a dis-

Fig. 5. The 43 RB unit at work, with radio-telephone van in the foreground

Fig. 6. One of the drill barges

charge of 300 cusecs; when the job is completed the same discharge will be obtained when the level of the Lower Lough is only 152 ft. O.D.

Although Cliff awaits the installation of a second power unit, the Erne scheme at present has a maximum capacity of 285 million units per year.

A remarkable tribute to the skill and judgment of the officials operating the power stations at the moment is the fact that despite the shallow channel and a dry year it was possible to work both power stations to capacity. The result of this good husbandry was that during 1953 the Erne power stations produced about 220 million units.

When the Erne scheme was proposed originally it was estimated that it would be an economic proposition if the demand for the whole country reached 800 million units. That figure has already been exceeded—in 1953 almost 1,000 million units were sold.

The Erne scheme will represent a considerable saving to Ireland's economy. Since it takes between 1·2 and 1·7 lb. of coal to produce one unit of electricity, the total saving on the import of coal must amount in a year to about three-quarters of a million pounds sterling. Then there is the additional saving in transport and handling. Furthermore, at 1d. a unit the Erne would have an income of £1 million a year!

A Water-Supply Power Plant

Loiza River dam, in Puerto Rico, which has just been completed, has been primarily designed to form a water reservoir for the city of San Juan, and produces a lake seven miles long holding 8,000 million gallons of water. The dam is 650 ft. long, has a crest of 50 ft., and eight 30 ft. high tainter gates for usable controlled storage above the crest of the dam. It now supplies San Juan with 30 million gallons of filtered water daily.

Power is being produced from this reservoir by three Francis turbines supplied by The James Leffel & Company. These units are rated at 1,550 h.p. at 327 r.p.m. under a head of 68 ft. and drive 1,000 kW generators. The turbines were completely built and assembled at the company's Springfield works before shipment, and form the latest of five installations installed by The James Leffel & Company in Puerto Rico.

A Long-Distance Transmission

In the Grand Falls district surveyors of the British Newfoundland Corporation Ltd. are investigating the possibility of transmitting power from there to Toronto and Ontario—a distance of some 1,000 miles —because it would be the cheapest site for a dam in Canada. Power capacities of five or six million horsepower have been mentioned.

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equalities in load up to about 2·5 times the value of the rated torque of the main motors. If the torque difference on one winch is greater than this value, the electrical coupling falls out of step and the drive comes to a standstill. In this way the equipment serves at the same time as a protection against overloading the driving motors.

Practical operation has shown that the drive described above acts very satisfactorily. It runs quite stably both at starting and with peak loads; it has no tendency to hunt, since the whole arrangement exhibits a positive damping; this is a fundamental requirement which must be fulfilled by any electrical coupling. The relatively simple operation of the electrical tie coupling and its advantages as described above lead more and more to its use for very varied industrial drives. For example, Oerlikon have recently supplied a similar electrical installation for a large pedestal crane.

Fig. 16. Hauling a penstock section in winter

High-Head Penstocks in the Rockies - III

Design and construction features of the penstocks for the Pole Hill and Flatiron power plants of the Colorado-Big Thompson project.

By PETER J. BIER

THE fabrication of the penstocks was divided up between the Alhambra and Richmond plants of the contractor, both of which were well equipped for such penstock work. This division of operations necessitated inspection service at both plants. The entire Pole Hill penstock and the downstream portion of the Flatiron penstocks, comprising the sections made from A212 steel, were fabricated at Alhambra, while the upstream portions of the Flatiron penstocks, made from A285 steel, were fabricated at Richmond. As steel deliveries were slow at the time, fabrication work was delayed to a considerable extent, and it took a little over a year to complete the shopwork. Fabrication was started with the upstream, low-head portions of the penstocks and continued downstream toward the high-head portions. Prior to production welding, the automatic welding process to be used by the contractor was tested. Two welded test plates were prepared by the contractor of each type of steel. The Bureau's engineering laboratories at Denver prepared the required tension and bend-test specimens and performed the tests. As the specimens showed the specified physical and chemical properties, and fractures through the welds disclosed uniformly fine grain structures, the welding process was approved. All welders engaged on this contract were qualified in accordance with AWS standard qualification tests.

Welding of Penstocks

Plates received from the steel mill were first flame-cut to the required width and length, and the edges were then prepared for welding. The plate edges were preformed in a press before being rolled to the required diameter. Plates of 120 in. width were generally used. After tackwelding the single longitudinal joint of a rolled plate, welding proceeded either manually or on a Unionmelt machine. The plates made from A212 steel were preheated prior to welding, a blowpipe being used for that purpose. Preheat temperatures from 175 to 250°F. were generally applied, the higher rates being used for the heavier plates.

As the specifications called for automatic welding

where practicable, manual welding, with a few exceptions, was used only for the circumferential joints of bend sections. First an inside pass was deposited, which in lighter plates was backchipped, and in heavier plates flame-gouged, before the joint was completely welded from the outside. Some of the longitudinal joints in the $\frac{5}{16}$ in. penstock shell were first manually welded from the inside, then backchipped and finish-welded from the outside on Unionmelt machines. Straight penstock sections, as a rule, were completely welded on Unionmelt machines, depositing first an inside pass, which was backchipped or flame-gouged before depositing the outside pass. No special edge preparation was used for the light plates up to and including $\frac{1}{2}$ in. in thickness. For heavier plates the edges were bevelled on the inside for a depth of about one-third the plate thickness, then rolled into a penstock course and tack-welded on the outside. After tack-welding, a heavy Unionmelt pass was deposited from the inside; the plates were then grooved on the outside by flame-gouging, which also removed the tack welds, and a Unionmelt pass was deposited. Prior to welding the edges of plates were cleaned by sand-blasting to remove all scale, slag, and other foreign matter which would affect the quality of the deposited weld metal.

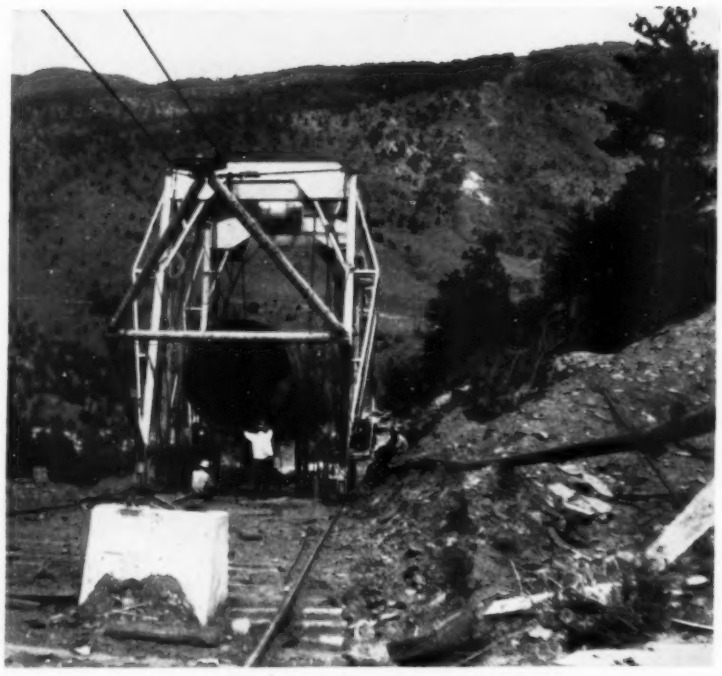


Fig. 17. Gantry crane at Pole Hill

As the penstock courses were rolled from one plate, only one longitudinal joint was required, which was located at quarter points of the circumference. Weld deposits were not peened but were cleaned between passes. Several straight courses were welded together into erection sections from 40 to 60 ft. lengths for field installation.

After the completion of an erection section all longitudinal and circumferential joints were radiographed by a technique to disclose quantitatively the size of defects with thicknesses equal to and greater than 2 per cent. of the plate thickness. The X-ray method was generally used except in some cases where the gamma-ray method proved to be more feasible or accessible. All radiographs were reviewed by the Government inspector, who determined the acceptability of the welds. Unacceptable defects, consisting generally of cracks, lack of fusion or penetration, excessive slag inclusions, porosity and undercuts, were removed by flame-gouging and the cavities were rewelded. Repair welds were re-radiographed to prove the quality of the repairs. Radiographic films of the slow-burning type were used, and all radiographs were marked to conform to a marking diagram which located each film in the pipe and joint. The radiographs became the property of the Government, to be kept on file for at least 10 years for future reference, as required by the Code.

The inner sleeves of expansion joints were cold-rolled similarly to the penstock sections. This, however, proved to be impracticable for the heavier outer sleeves ranging from $2\frac{1}{4}$ to $2\frac{3}{4}$ in. in thickness, and consequently the plates for these sleeves were hot-bent and rolled. Plates of excess thickness had to be used to provide the extra metal required for the forming and machining operations. Prior to rolling, the flat plates were flame-cut to size in two halves, and the edges prepared for the type of welded joint to be used between the two halves. Then the edges of the plates were heated in a furnace to a cherry-red colour and bent to circular shape in a press. After this initial forming operation, each plate was heated throughout and rolled into a half circle. The two halves were then welded into a complete circle, the welds radiographed and the sleeve stress relieved, after which it was machined where required. Each sleeve was again stress relieved after it was welded to its respective penstock section.

Riveted Field Joints

The rivet holes in penstock sections with riveted field girth joints were drilled in the flat plate before rolling. Holes were drilled separately in the shell plate and butt strap. All holes were countersunk on the inside of the penstock shell, and rivets with manufactured countersunk heads were used to reduce hydraulic losses in the penstocks. On the outside of the butt straps, steeple heads were formed during riveting. As riveting for pipes and penstocks is rarely used to-day, and has become practically a " lost art," some experimental riveting was necessary before production was started. The following drilling, reaming, and riveting procedure was finally adopted:—

a. Approximately 20 per cent. of the rivet holes for the $1\frac{1}{4}$ in. rivets were drilled to $1\frac{1}{16}$ in. diameter and

for the $1\frac{1}{8}$ in. rivets to $\frac{15}{16}$ in. diameter in both the butt strap and penstock shell before the plate was rolled into circular shape.

b. After rolling, the butt strap was assembled on the penstock shell by inserting fit-up bolts in the $1\frac{1}{16}$ in. or $\frac{15}{16}$ in. holes; then remaining holes were drilled through the butt strap and penstock shell. The holes for the shop rivets were drilled to the finished diameter of $1\frac{5}{16}$ in. for the $1\frac{1}{4}$ in. rivets and to $1\frac{3}{16}$ in. for $1\frac{1}{8}$ in. rivets, while the holes for the field rivets were drilled to $1\frac{1}{4}$ in. and $1\frac{1}{8}$ in. diameter respectively, leaving $\frac{1}{16}$ in. for field reaming. Drilling was not performed continuously but in stages of three rows of holes each, and every third hole was provided with a fit-up bolt for pulling the plates into close contact.

c. The butt strap was removed from the penstock, then the rivet holes were countersunk on the inside of the shell, and all chips and burrs were removed. After this operation the butt strap was reassembled on the penstock shell, using fit-up bolts in every third hole, and all rivet holes were checked for alignment with a plug gauge permitting an offset tolerance of 1/64 in. between mating holes.

d. After the above preparatory work, riveting proceeded by means of a specially constructed bulldozer. This was a C-shaped steel casting with a cylinder operating the rivet die for the steeple head. A water pressure between 1,100 and 1,200 lb. per sq. in. was maintained in the cylinder, and release of the die effected by means of air pressure. The bulldozer was suspended from a cable, and during riveting was centered on the joint to be riveted while the penstock section was being rotated on rollers. A small gas-fired furnace was used for heating the rivets. At the Richmond plant where a bulldozer was not available, riveting proceeded manually, using the double-gunning method similar to the field riveting. Notwithstanding all the care and precautions taken before the actual riveting operations, some of the rivets did not meet the tolerance requirements in eccentricity of head, or were not tightly driven. Such rivets were removed and replaced with new rivets. Removal was accomplished by flame-cutting the heads from the shank and driving the rivets out of the hole. Damaged holes were rereamed before driving the replacement rivets.

The butt straps were made in two halves, one half to be riveted to the top of one section, the other half to be riveted to the bottom of the adjoining penstock section. Riveting proceeded in the shop on one side of each half of butt strap and in the field on the other side of each half, except that the rivets for a length of 18 inches at each end of a butt strap section were omitted temporarily, until the two halves had been welded into a ring during installation. This 18 in. of unriveted length was to absorb the shrinkage stresses due to welding the two halves of the butt strap into a continuous ring. Before field riveting, the holes were reamed to the finished diameter.

Fig. 18. Downstream ends of Flatiron penstocks, showing Dresser couplings

Stress Relieving and Hydrostatic Testing

Penstock sections fabricated from A285 steel over 1 in. thickness and all sections fabricated from A212 steel were thermally stress relieved after the completion of radiographic inspection and repair welding. This was done in a special stress-relieving furnace, which at the Alhambra plant was 75 ft. long and of ample cross section to accommodate the diameters and the 60 ft. section lengths. The furnace was gas-fired and temperatures between 1,100 and 1,200°F. were maintained for a period of 1 hour per inch of maximum plate thickness in pipe section. Heating above 600° was done at a rate not exceeding 400° per hour, divided by the maximum plate thickness, but in no case at more than 400° per hour. Cooling in the furnace was at a rate not in excess of 500° per inch of maximum plate thickness, but

in no case at more than 500° per hour. Below 600°F. the section was cooled to normal temperature in still air. The time and temperature cycle during the heat treatment were recorded graphically by means of an automatic control device. These records were reviewed by the inspector to determine the adequacy of each stress-relieving operation.

After stress relieving, each individual erection section was subjected to a hydrostatic pressure test in a specially designed testing machine. A test pressure of one and one-half times the design pressure was applied to produce the specified test stresses of 20,000 and 26,000 lb. per sq. in. respectively, for the A285 and A212 steels. The 60 ft. erection sections were tested in two halves, as the testing machine could not accommodate sections of that length. An internal test head with a U-shaped rubber gasket was used inside the pipe to maintain the required test pressure, which was produced by a pump. Bend sections were tested by means of test heads welded to the ends. Pipe sections with expansion joints were tested by temporarily connecting the inner sleeves to the adjoining penstock sections with plates welded across the ends of both. Leakage in the expansion joints was eliminated by further tightening of the flax packing. With the successful testing of an erection section, it was ready for loading and shipment to the project.

There was considerable variation in plate thickness. Variations, however, were usually on the plus side, running up to $\frac{1}{16}$ in. for plain plates and up to $\frac{1}{8}$ in. for the chromium-clad inner sleeves of the expansion joints. These variations in plate thickness increased the contractor's difficulty to meet the specified tolerances in plate alignment. They also changed the grip length for plates to be riveted, and made it more difficult to drive rivets with uniform heads. A number of plates disclosed rolled-in defects requiring repair. Some defects were discovered only after the penstock sections had been completed. (These difficulties with the steel plates prompted the Bureau to initiate mill inspection of plates for important pipelines.)

The steel mills apparently had at that time discontinued the practice of normalising steel plates over 2 in. thickness to obtain grain refinement. Therefore, the contractor applied this heat treatment, but extended it to all plates over $1\frac{3}{4}$ in. thickness, using his stress-relieving furnace for that purpose.

Installation

Completed penstock sections were shipped by rail to Wilds Spur siding, located about 5 miles west of Loveland, Colorado. From here the sections were transported to the project on trucks and trailers over mountain roads especially constructed for that purpose. Fig. 16 shows the hauling of a penstock section over the snow-covered road during the winter season. At the penstock sites the sections were unloaded by locomotive crane. The Pole Hill sections were loaded on a specially constructed gantry crane as shown in Fig. 17. This crane was operated on a track of 15 ft. 6in. gauge straddling the penstock. A motor-driven hoist located at the intake structure lowered the gantry with a wire rope to the point of installation. At the Flatiron site, the penstock sections were placed into the line directly with the locomotive crane. Although the concrete support piers and the lower portions of the anchors had been constructed

Fig. 19. Partially completed field girth joint

beforehand, the penstock sections were first placed on temporary timber supports until the rockers could be installed and grouted into recesses provided in the concrete piers. Before grouting, the rocker bases were set in place in accordance with the prevailing temperature in accordance with a temperature chart. The penstock load was not transferred from the temporary timber supports to the rockers until the grout had set sufficiently to carry the load.

Installation started with the bend sections at anchors, which were set to line and grade, then concreted into the second-stage concrete of the anchors. After placement of the bends, installation proceeded from the anchors towards the expansion joints which also served as make-up joints. Installation at Pole Hill was interrupted by a failure in the hoist brake, which caused the loaded gantry to run downhill into the rocky hillside near the penstock. The impact damaged the gantry and a portion of the penstock section loaded on it. Although it was possible to repair the penstock section by replacing the damaged course with a new one, the gantry and hoist had to be replaced with new, improved equipment which operated satisfactorily for the remaining installation work.

Field welding was limited to the girth joints of pipe sections fabricated from A285 steel. The field girth joints in the penstock fabricated from A212 steel were riveted, except in the downstream end sections of the Pole Hill penstock, in the backfilled sections between anchors Nos. 14 and 15 of Flatiron penstock No. 1, and in all backfilled sections of Flatiron penstock No. 2, which were sleeve-coupled, using Dresser couplings. Fig. 18 shows the sleeve-coupled downstream sections of the Flatiron penstocks. All field welding was manual. Before welding, the pipe sections were set to line and grade on temporary timber supports, then aligned at the edges and tack-welded. Each layer of weld metal was cleaned of slag and other deposits before applying the succeeding layer. Peening was not resorted to. The backside of double-welded butt joints were flame gouged or chipped to sound metal before depositing weld metal

from that side. After complete welding of a joint, all coarse weld ripples were removed by grinding to improve radiographic contrast. All welded field girth joints were radiographed; unacceptable defects were removed by flame gouging and replaced with sound welds which were re-radiographed to prove the quality of the repairs.

The riveted field girth joints used between pipe sections fabricated from A212 steel were partially completed in the contractor's shop, as shown in Fig. 19. Riveting was completed in the field during installation. After the alignment of adjoining pipe sections, the two halves of the butt straps were bolted to the pipes with erection bolts, then the rivet holes were reamed to the final diameter of $1\frac{3}{16}$ in. for the $1\frac{1}{8}$ in. rivets, and to $1\frac{5}{16}$ in. for the $1\frac{1}{4}$ in. rivets. Before riveting, the rivet holes were chamfered from the outside to prevent sharp fillets under the driven head. The field rivets were heated in a portable coke-fired, forced-air forge located outside the pipe near the joint to be riveted. After heating, the rivets were conveyed to the inside of the penstock by means of a pneumatic flexible metal tube. They were inserted into the holes from the inside of the pipe and driven by the double-gunning method. Fig. 20 shows riveting in progress on a field girth joint. Riveting at first was not as good as desired, since the use of such large-size rivets made driving under field conditions rather difficult. As a result, many rivet heads were loose or not well formed, and had to be removed and replaced with new rivets. Technique improved, however, as riveters acquired more experience.

Installation proceeded during the winter months as fair weather prevailed generally throughout the period. The Pole Hill penstock, a photograph of a portion of which is shown in Fig. 21, was completed

Fig. 20. Field riveting in progress

first, and was filled with water for the leakage test called for in the specifications. This test was made under the static head to determine primarily the watertightness of the riveted field girth joints. As a slight seepage was observed through a large number of rivets during the test, it became necessary to resort to calking of the affected rivetheads to make the joints watertight. Some of the expansion joints and Dresser couplings also developed slight leakage during the test. In the expansion joints, the leakage was arrested by further tightening of the packing gland bolts to increase the compression in the flax packing. Leakage in the Dresser couplings was limited to the downstream end of Flatiron penstock No. 2. It was caused by settlement of the backfill soil on which this coupled section of the penstock was supported. Each coupling was tightened before and during the leakage test by means of torque-control wrenches furnished by the coupling manufacturer. After completion of the leakage test, the penstocks were drained and backfilled with compacted earth. A backfill of about 21 ft. was placed over the top of the downstream end of the Flatiron penstocks. Soon after that water seeped into penstock No. 2 through one of the couplings. The source presumably was a nearby spring which saturated the earthfill. An offset in excess of $\frac{1}{2}$ in. was disclosed between the adjoining penstock sections at the coupling, which distorted the gasket and caused the leak. The excessive offset, being more than double the permissible value, was due to settlement of the soil under the penstock sections, which no doubt was induced by the heavy compacted backfill placed over the penstock. As the coupling was not accessible for further tightening, it was necessary to re-excavate this portion of the penstock. With no assurance against further settlement, it became necessary to realign this section of the penstock and construct two reinforced-concrete support piers with their bases carried down to rock, to prevent excessive settlement in the future. A similar restoration was necessary for the downstream end section of penstock No. 1, which has riveted field girth joints. This penstock section showed a deflection of $\frac{3}{4}$ in., caused no doubt by the 21 ft. backfill. To prevent similar deflections during operation and consequent dangerous rise in the beam stress, this penstock was also re-excavated and reinforced with two concrete support piers. It was also necessary to calk some rivetheads showing leakage before it was backfilled again. With the backfill removed, the deflection in the penstock section decreased to less than half the value under backfill. This furnished further proof that the offset and leakage in the coupling of penstock No. 2 and the deflection and rivet leakage in penstock No. 1 were due to the unstable soil support combined with the abnormally high backfill load. It may be said in general that since the couplings are not designed to carry beam loads between adjacent sections of a penstock, the sections without stable soil support must be provided with other means of support between couplings to assure watertight connections.

Coatings

After completion of the leakage tests, the penstocks were painted. This work was subcontracted to the O'Connor Rustproofing Company of Phoenix, Arizona. Samples of paint materials were tested prior

to application in the Bureau's engineering laboratories. The exterior surfaces of the portions of the pipe to be backfilled with earth were sandblasted, coated with coal-tar primer and enamel, then wrapped with asbestos felt and whitewashed. Interior surfaces of the penstocks were sandblasted, coal-tar primed, and enamelled. Some difficulty had been experienced with the slow drying of the primer, which in part was due to adverse weather conditions. In some cases, it took up to two weeks to dry the primer sufficiently for the application of the enamel to obtain a good bond. It was necessary to reduce the thickness of the primer and provide better ventilation, also to change the primer itself. The exterior surfaces of the exposed portions of the penstocks were sandblasted, primed with red lead, and coated with two spray coats of phenolic resin aluminium paint. On the Pole Hill penstock, one coat of red lead was brushed on, and on the Flatiron penstocks two spray coats of red lead were applied. Defective areas were cleaned and recoated. All coating was tested by electrical flaw detectors before final acceptance. Good temperature control during heating of the enamel produced a very plastic enamel lining.

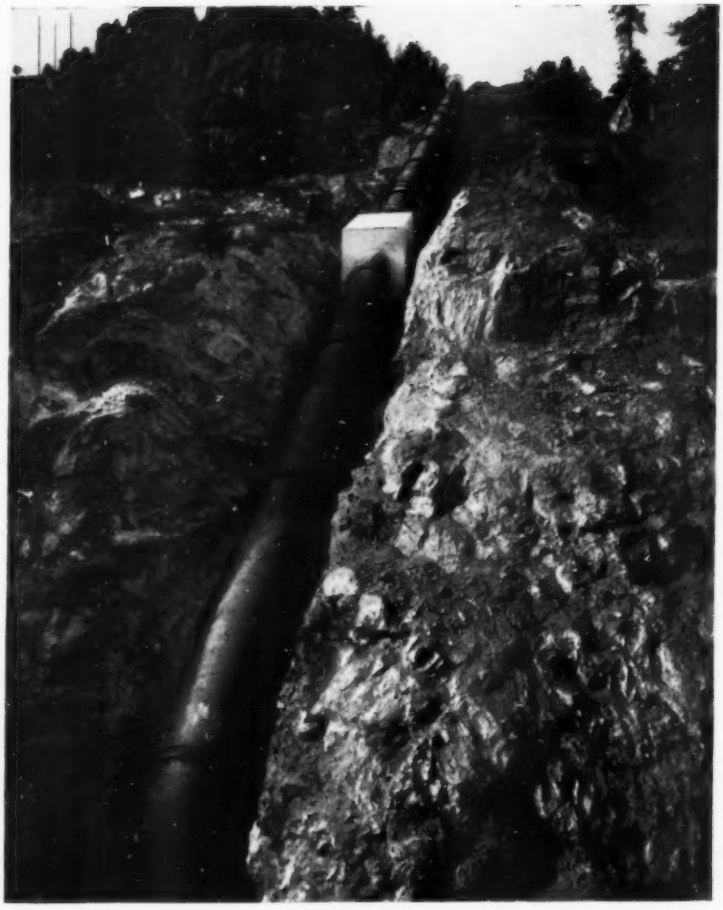


Fig. 21. A portion of Pole Hill penstock

Control of fabrication, welding, installation, and painting was maintained by qualified inspectors assigned to the job. It was the inspector's responsibility to follow all operations in the shop and field, examine the radiographs and determine the necessary weld repairs, review stress-relieving operations, and witness all hydrostatic pressure tests. The inspector was also required to witness the preparation and welding of test plates in connection with procedure and welder qualification tests, and the welding of test plates required for the control of production welding. These manifold duties required the presence of an inspector during most of the time when production was in full swing. The principal inspection work at the contractor's Alhambra plant was performed by P. W. Steelsmith, and at the Richmond plant by Victor Barth and J. P. Jordan.

The penstocks were designed by engineers of the Steel Pipe and Penstock section under the direction of the author, and under the general supervision of J. K. Richardson, Chief of the Mechanical Branch. All design work was at the time under the general direction of W. H. Nalder, Chief Designing Engineer, who was succeeded by K. B. Keener, and all construction work was under the general direction of Grant Bloodgood, at the time Chief Construction Engineer, now Associate Chief Engineer. L. N. McClellan, Assistant Commissioner and Chief Engineer, was in charge of all design and construction activities. Construction Engineer G. H. Highley had charge of field installation, and G. L. Yetter was Resident Inspector for the Bureau. The Southwest Welding and Manufacturing Company of Alhambra, California, was the general contractor for the penstocks, with responsibility for all fabrication and installation work. All earth and concrete work was sublet to Winston Brothers Company of Minneapolis, Minnesota. Southwest's personnel included R. W. Cutler, Chief Engineer, who was succeeded by S. R. Lanier. R. S. Edens was Project Engineer. Shop fabrication at the Alhambra plant was under the supervision of B. H. Gritzmaker and S. Marinovich, and at the Richmond plant under L. Beck. R. Garity was field superintendent in charge of penstock installation, assisted by A. H. Zimmerman, Field Engineer. R. F. Rasey and F. G. Peterson were manager of operation and field superintendent respectively for the Winston Brothers Company.

NOTE.—The author would like to draw attention to an addition that should be made to the Table in Fig. 15 in the second part of his article on page 434 of our November issue. The Table should have the following headings reading from left to right:—

I.D., T. Type of jcint, Rivet dia., No. of rivets per row. A, B, C, D, R.

Tungatinah Power Plant

Further to our article on hydro-electric power developments in Tasmania in the September issue of last year, we now give particulars of the power units of the Tungatinah station.

THE river system of Tasmania, which incorporates many natural lakes, affords a potential water-power development approaching 3½ million h.p. at 50 per cent. load factor. As the population of Tasmania is at present less than 350,000 persons a potential of more than 10 h.p. per head must rank as one of the highest in the world, and even a substantial increase in population would scarcely invalidate this claim.

The first development of water power in Tasmania dates from 1892 when the Launceston City Council began work on the Duck Reach scheme on the South Esk river, and since that date developments have taken place at an ever-increasing rate, culminating in the harnessing of the Derwent Catchment area (Fig. 1). This extensive project embraces the Great Lake scheme which includes the Shannon and Waddamana power stations, and schemes for Butlers Gorge, Tarraleah, Tungatinah, Lake Echo and Wayatinah.

Referring to Fig. 1, two and a half miles upstream from the Lyell Highway, the Pine Tier dam has been built across the Nive river to create a new lake and to divert the flow through eight miles of concrete flumes and canals to the Bronte Lagoon. From there, the water is led by canals to artificial storages at lakes Bradys and Binney, whence it flows into the Tungatinah Lagoon. A tunnel with a cross section of 231 sq. ft. has been driven through the hills to supply five steel penstocks each 3,200 ft. long and having a maximum diameter of 90 in.

The Pine Tier dam, which is 120 ft. high, taps a catchment area of 321 sq. miles having an average annual run-off of 590 cusecs. A weir constructed across the Clarence river diverts additional water to Bronte Lagoon, through a wood-stave and steel pipeline 5½ miles long and 63 in. diameter, and having a capacity of 190 cusecs. This weir diverts a catchment of some 45 sq. miles and a small dam will ultimately be built across Laughing Jack Lagoon to provide storage capacity for regulation purposes. The average flow diverted to Bronte Lagoon will be 120 cusecs.

Finally, on the completion of the second stage of the scheme, which includes the provision of storage at Lake Echo, the construction of Lake Echo power station and the diversion of the river Dee, will still further augment the water supply for the Tungatinah turbines. A rock and earth fill dam, 60 ft. high, is being built across the outlet from Lake Echo. This natural lake has a surface area of 11 sq. miles and the total storage available will be 600 sq. mile/ft. The headwaters of the Little Pine and Ouse rivers will be diverted into Lake Echo, and a canal having a capacity of 800 cusecs will lead from the lake to a steel penstock of 114 in. dia., which will supply Lake Echo power station. A dam, 50 ft. high, now being built across the river Dee adjacent to the Lyell Highway, will create an artificial lake below the power station and will be known as the Dee Lagoon. From here a 2¼-mile tunnel of 800 cusec capacity will carry the water to Brady's Lake and thence to Tungatinah

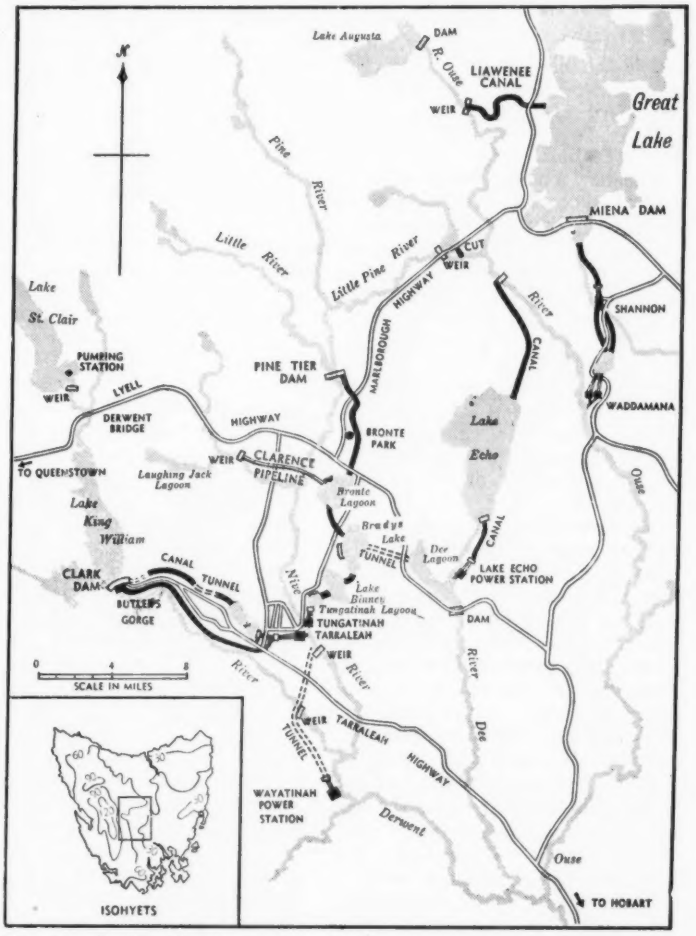


Fig. 1. Hydro-electric power development, river Derwent and tributaries

Fig. 2. Upstream view of Nive river showing Tarraleah station in foreground and Tungatinah behind in course of construction

power station. The catchment area below Lake Echo which will be brought into service by this dam has an extent of 51 sq. miles and has an average annual run-off of 50 cusecs.

Power Station

The new power station at Tungatinah is of steel-frame and corrugated-iron construction and is situated on the left bank of the Nive river about 400 yards upstream from, and on the opposite bank to, the Tarraleah power station. The generator floor at RL.1152 ft. 2 in. is at the top of the generator stator, and an intermediate floor is provided at RL.1138 ft. The turbine floor, in line with the centreline of the spiral casing, is 26 ft. 5 in. below the generator-floor level. To facilitate removal of the runner a fourth floor is provided at RL.1119 ft. 9 in. at the junction of the removable suction cones with the suction linings. The vertical distance from the generator-floor level to the bottom of the draught tubes is 38 ft. 11 in.

In order to provide an open and unobstructed setting, and in particular, to avoid enveloping the turbines in a massive concrete support, the generators are supported on reinforced concrete walls placed between each turbine. The concrete could thus be placed before erection commenced, which made an uninterrupted erection programme possible, once the units were on site.

Hatchways, each 10 ft. 6 in. by 6 ft., are provided for each unit on the upstream side of the station, through which were lowered the inlet valves and turbine parts. Smaller hatchways each 8 ft. 6 in. by 5 ft. 6 in. are also situated on the downstream side to enable the turbine pumping sets to be placed in position. In this way a very neat layout is obtained, only the exciters, turbine-governor actuators, instrument panels and cabinets being visible above the generator-floor level.

Generators

The generators consist of five vertical-shaft hydro-alternators manufactured by The General Electric Co. Ltd., England, and supplied by its Australian representatives, the British General Electric Co. Pty. Ltd. Each machine is continuously rated in accordance with B.S.S.266 for the following duty:—

Output	25,000 kW/31,250 kVA
Normal speed, r.p.m.	600
Runaway speed, r.p.m.	1,050
Voltage	11,000
Frequency, cycles per second	50
Phases	3
Flywheel effect, lb-ft.^{2}	1,040,000

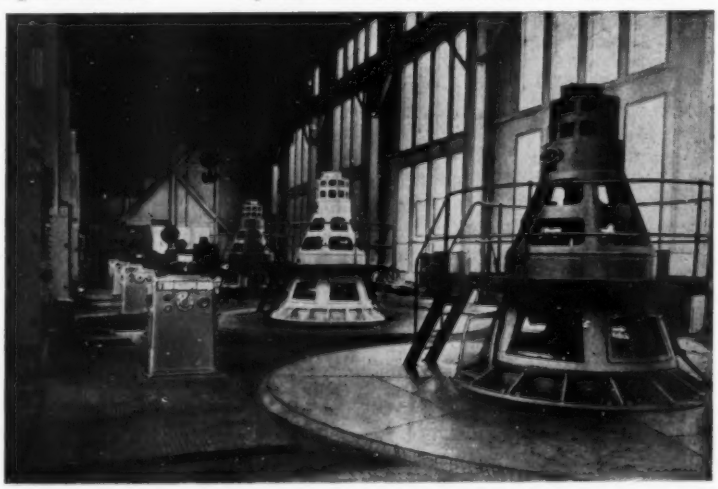


Fig. 3. Interior view of Tungatinah station

Mounted above and directly coupled are the main exciter, pilot exciter, and permanent magnet governor alternator, the whole assembly forming a self-contained unit. To comply with transport requirements, the alternators, which weigh over 175 tons, were constructed in such a manner that the weight of any single part was limited to 35 tons. The stator was split and despatched in two halves; the poles with their field coils were removed from the magnet wheel; the exciter armatures and permanent-magnet alternator rotor formed a self-contained assembly; and the radial arms supporting the top thrust-bearing housing were also dismantled and shipped separately.

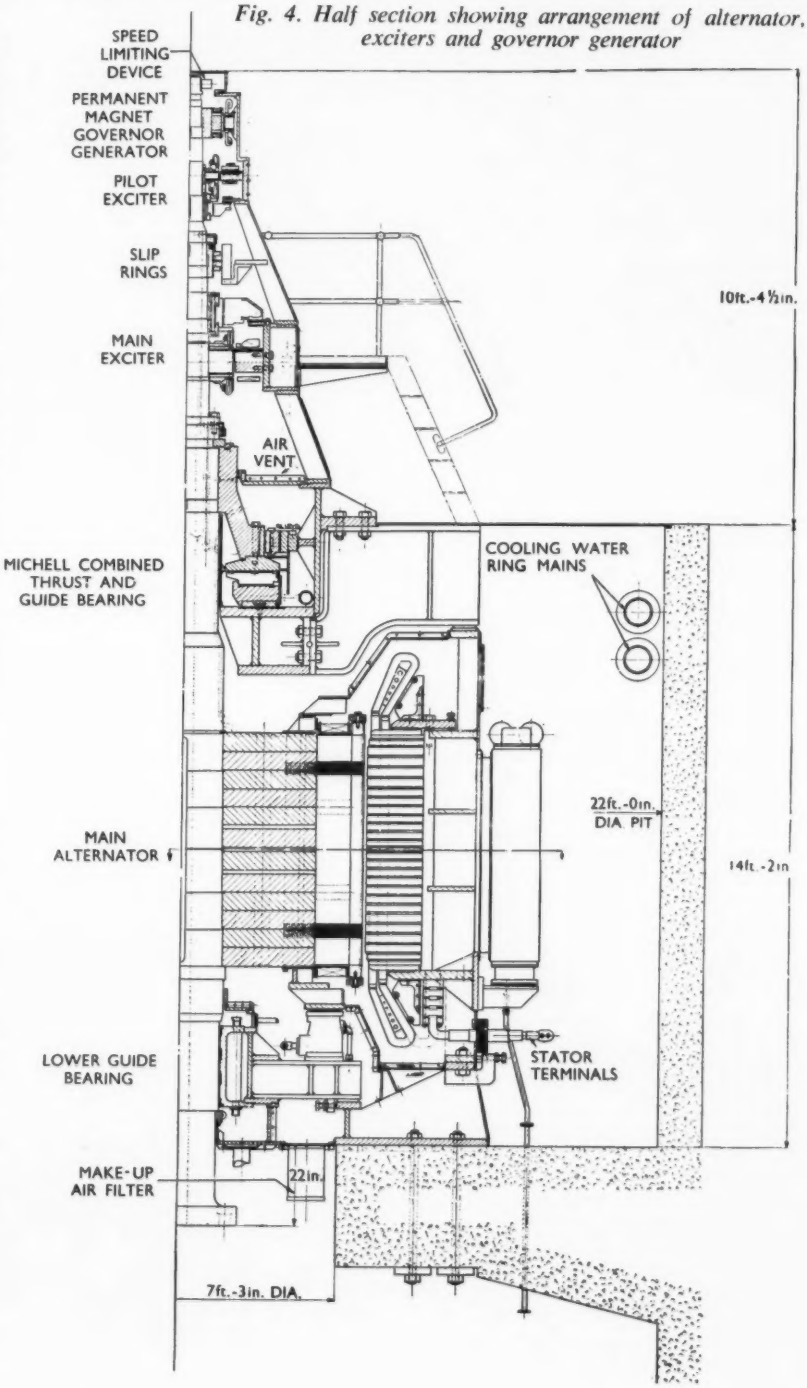
The general arrangement of the alternator, exciter and permanent magnet governor generator is shown in half section in Fig. 4.

The stator frame is a fabricated structure of octagonal shape, built in two halves which are bolted and dowelled together. The construction of the core follows standard practice, segmental stampings being secured by dovetailed keys bolted to longitudinal ribs within the frame. For these machines a two-layer diamond-type winding was used, the insulation being of mica and micanite throughout. End windings are strapped to Permali supports fixed to the core-clamping plates, the connections being brought out through an insulating plate situated near the bottom of the frame. A view of the stator in course of winding is shown in Fig. 5. Aluminium guards provide adequate protection of the end windings and serve also to guide the cooling air through the machines.

Six thermo-couples, embedded in the stator, enable the temperatures of the core and windings to be recorded on a remote temperature indicator mounted on the turbine gauge panel.

The rotor is designed for a safe overspeed of 75 per cent., i.e. 1,050 r.p.m. Shaft and coupling are forged in one piece; twelve plates are shrunk and keyed on the shaft to form the rotor body into which the laminated poles are T-slotted and secured by taper keys. Each pole winding is subjected to heat and hydraulic pressure to form a solid coil in which risk of movement of individual turns is eliminated. Circumferential movement is prevented by duralumin wedges fitted between adjacent pole windings and secured to the rotor body (Fig. 6). Copper rods in the pole faces are brazed into copper

Fig. 4. Half section showing arrangement of alternator, exciters and governor generator



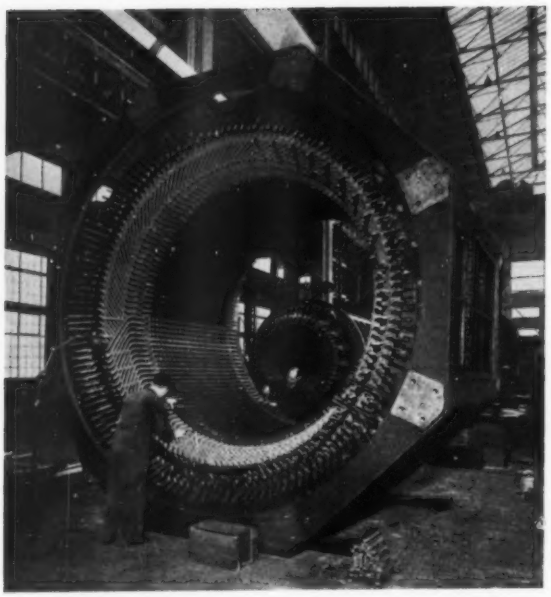


Fig. 5. Stator in course of erection

plates which are connected together by duralumin rings to form the squirrel-cage damping winding.

Two centrifugal fans, one at each end of the rotor, circulate the cooling air through the machines, the lower fan embodying the braking ring as seen in Fig. 6. The rotor is supported by a thrust and guide bearing of the Michell type which is designed to carry a toal load of 270 tons, representing the weight of the rotor and the external thrust produced by the water turbine. The housing is spigoted and bolted to the thrust-bracket assembly which is bolted to the stator frame and located by tapered dowels. Doors in the housing give access to the thrust pads for maintenance purposes. The bottom guide-bearing housing is centralised and located by jacking screws, no spigot being used. In order to obviate any risk of current circulating through the rotor shaft, the thrust and guide bearings are insulated from the supporting structure.

The armatures of the main and pilot exciters, the rotor of the permanent magnet alternator for supplying power to the turbine governor motors, and the centrifugal overspeed device are mounted on a forged steel shaft (Fig. 4) which is solidly coupled to the main alternator shaft. The main exciter is separately excited with a counter shunt winding, while the pilot exciter is compound wound, initial adjustment of the field current of this machine being effected by a shunt field regulator.

The brushgear of both exciters and the alternator sliprings is mounted within a fabricated stool situated between the two exciters as shown in Fig. 4, the brushgear being supported on adjustable yokes. The cupro-nickel sliprings are mounted on an insulated hub which is pressed on and keyed to the shaft, while adequate creepage is given by an insulating barrier fitted between the rings. Doors in the stool give easy access from a raised platform which surrounds the exciter assembly.

The cooling system forms a closed air circuit in which cool air is drawn from the alternator pit and forced through the machine, the warm air being returned to the pit through the cooler which is arranged in eight sections mounted around the shell of the machine as seen in Fig. 7, which shows the alternator erected on the works test bed. Temperature detectors in the air inlet and outlet are connected to a Cambridge instrument on the turbine gauge panel. In addition, two Budenberg mercury-in-steel thermometers, fitted with adjustable maximum contacts, operate alarms if the inlet and outlet air temperatures exceed predetermined values, the thermometer dials being mounted on the turbine gauge panel.

The coolers were designed and manufactured by The Premier Cooler and Engineering Co. Ltd., each cooler section forming a self-contained unit and comprising a nest of tubes around each of which a heat transfer element is wound. Cooling water is supplied from a 7 in. dia. ring water main situated at the top of the alternator pit. With a cooling water inlet temperature of 27°C. and a rate of flow of 616 gallons per minute, the complete cooler assembly will reduce the temperature of 63,000 cu. ft. of air per min. from 56°C. to 35°C. The capacity of each section is such that any seven of the eight units are capable of dissipating the full load losses (approximately 700 kW) so that any one section can be isolated for maintenance purposes with the machines running at full load.

Flow lubrication is used for the guide and thrust bearings of the alternator. Oil from a 1,000 gallon tank is circulated by a motor-driven pump through an Auto Kleen strainer and Serck oil cooler to the bearings, whence it returns by gravity to the storage tank.

The pump has a capacity of 180 gallons per min. at 75 lb. per sq. in. pressure, and is driven by a 20 h.p., 415 volt, squirrel-cage motor. A duplicate standby pump is provided and is brought into operation automatically by the action of a flow relay should the rate of flow fall below a preset value. As an additional precaution, the standby pump is driven by a 20 h.p. motor, fed from an independent source of direct current, thereby eliminating any risk of loss of oil to the bearings in the event of a failure of the alternating supply. A standby cooler is also installed

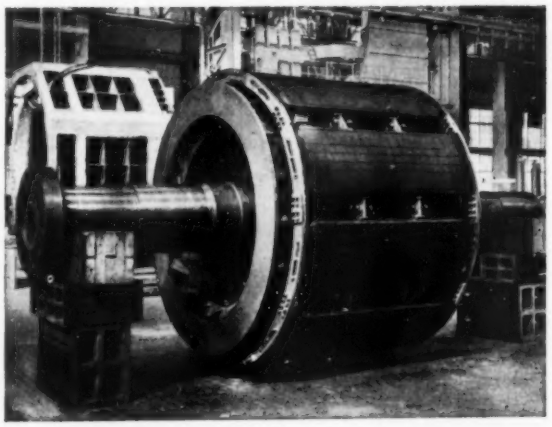


Fig. 6. Combined fan and brake ring on rotor

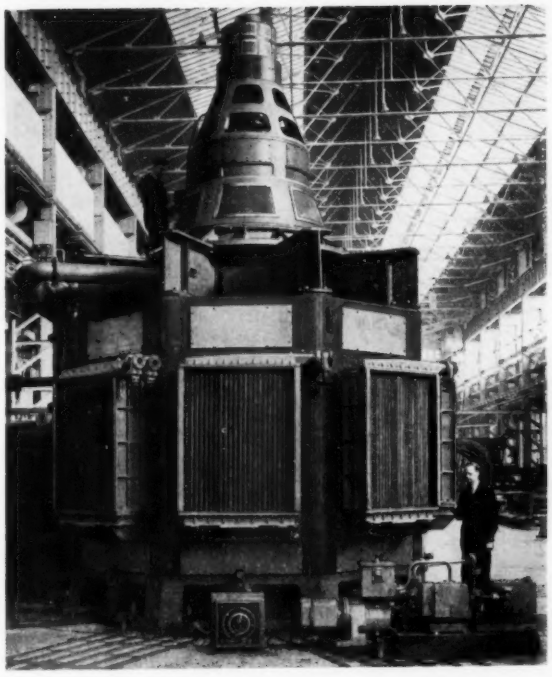


Fig. 7. Alternator on works test bed

so that servicing may be undertaken while the alternator is running. Each cooler is designed to dissipate 18,000 B.Th.U. per minute, and will reduce the oil temperature from 55°/60°C. to 45°C. when fed with cooling water at 27°C. and handling 165 gallons of oil per minute.

Budenberg mercury-in-steel thermometers are fitted to all bearings and are connected through capillary tubing to indicating dials on the turbine gauge panel. Each thermometer has two contacts which can be adjusted independently and give an alarm if the bearing temperature reaches 68°C., or operate the emergency trip circuit and shut down the set if the temperature rises to 80°C.

The braking and jacking equipment was supplied by Jones Tate & Co. Ltd., Bradford. It comprises five rams, equally spaced and acting upon the brake ring which, as previously mentioned, is fabricated integrally with the lower ventilating fan on the magnet wheel. The top of each ram forms a flat plate which carries a heavy brake lining.

Although the braking system and the jacking system are interlinked, they are operated independently of each other. For braking, oil at 285 lb. per sq. in. from the turbine governor system passes through a reducing valve where its pressure is dropped to 50 lb. per sq. in. Between this valve and the ram cylinders is a solenoid-operated valve which opens automatically when the magnet wheel has slowed down to about half-speed. Oil is then admitted to operate the rams which apply the braking torque to bring the machine to rest.

By means of this jacking system the magnet wheel can be lifted when the machine is at rest to allow an unrestricted flow of oil through the thrust bearing before starting up, and it also enables essential maintenance work to be undertaken. For jacking, a much higher oil pressure is required and this is obtained from a Towler Bros. Electraulic high-speed multi-ram pump which delivers oil at a pressure of 1,650 lb. per sq. in. Mechanical stops limit the upward travel of the rams and are set to ensure that each ram rises to exactly the same height. A system of electrical interlocks ensures that the machine can-

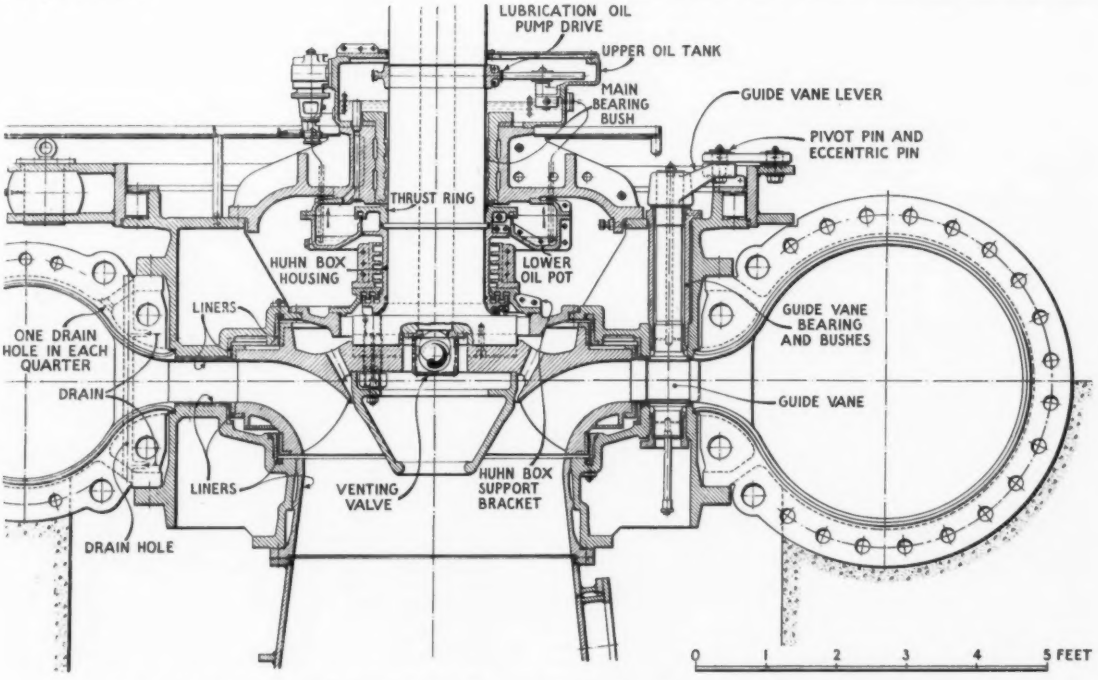


Fig. 8. Section through one of the Boving 35,000 h.p. 600 r.p.m. 950 ft. head turbines

Fig. 9. Runner of the first Boving turbine

not be started up unless all the rams are in their fully lowered position. Oil from the rams returns to the jacking system through a high pressure, solenoid-operated release valve.

Hand-operated sustaining screws are provided for supporting the magnet wheel in the raised position. These screws are interlocked with the rams in such a manner that they cannot be operated until the magnet wheel is slightly raised so that incorrect operation is impossible. They also actuate the electrical interlocks associated with the rams.

For both the braking and jacking systems the solenoid-operated valves are of the semibalanced type and operate practically instantaneously. They are spring closed and are so arranged that the oil pressure assists closing, thereby ensuring that the valves seat tightly. The solenoids operate on a 125 volt d.c. supply and are continuously rated, economy resistances being provided to reduce automatically the consumption of the solenoid to about 10 per cent. of full load immediately before the solenoid reaches the end of its opening stroke.

The machine is operated from the turbine gauge panel on which are mounted all the controllers associated with the various oil pumps, braking and jacking systems, valves and so forth, temperature indicators and alarms for bearing oil, alternator windings and cooling air, as well as lamps to give a continuous indication of the operation of the complete plant.

Turbine Plant

The turbines are of the vertical Francis type and were designed by Boving & Co. Ltd., and manufactured by their sub-contractors, Peter Brotherhood Ltd., except for the runners, which were made by Markham & Co. Ltd. Each of the five machines is designed for an output of 35,000 h.p. under a net head of 950 ft., at 600 r.p.m. These machines are notable in that they are at present the highest head Francis

Fig. 10. Spiral casing in course of erection on site

turbines operating in Australasia, and it is believed the highest head turbines of this type yet manufactured in the United Kingdom. Fig. 8 shows a cross-sectional view of the turbines.

The spiral casings and stay rings are of cast steel, each made in four sections with heavily flanged bolted joints. The horizontal flanges to which the top and bottom covers are bolted provide additional strength and rigidity, the seal between the casing and covers being effected by rubber rings fitting into wedge-shaped grooves. Before any grouting was done under the spiral a hydraulic test was carried out to ensure that all joints were satisfactory.

The stainless-steel guide vanes are cast integrally with the top and bottom spindles, and are mounted in twin journal bearings on the top and bottom covers. Each vane is individually adjustable to ensure that the clearance between top and bottom covers is distributed satisfactorily, and adjustable eccentric pins are provided at the connection of the breaking links with the regulating ring to ensure correct closure of the guide wheel.

A special feature of the turbine design is the large roller bearing which is incorporated in the regulating ring; this reduces friction to a minimum, and eliminates sticking when the turbine has been running for long periods without changes in load. It will be noted from Fig. 8 that the regulating ring and guide vane levers and links are mounted outside the guide-vane pitch circle, thus allowing ample access to the inner part of the turbine, and in particular to the Huhn packing and turbine guide bearing. The top and bottom covers, manufactured from cast steel, are fitted with stainless steel rings to match those on the runner, together with a stainless steel throat ring and stainless clad steel guide vane cheek plates.

Particular care was taken with the runners, which are of solid cast stainless steel, accurately machined, ground and finely polished to suit the water velocities incidental to the high head. Leakage losses and hydraulic thrust are minimised by the arrangement of the stainless-steel sealing rings which match the similar rings on the top and bottom covers. The rings are attached with stainless steel counter-sunk screws, and are thus readily renewable. In order to avoid damage to the guide vanes and runners, caused by gravel or other debris from the unlined portion of the tunnel, the usual method of drying out the generators by running the machine with the guide vanes set at the "no load" position was not adopted. Instead a d.c. generator set was used to pass current through the windings.

The turbine shaft is a solid steel forging, the runner being attached to the lower coupling by means of clearance bolts, locating spigot and cross keys to permit easy removal and replacement. The lubricating system of the white metal lined turbine guide bearing consists of a pump, gear-driven from the turbine shaft, together with a standby d.c. electric motor-driven pump.

Leakage between the turbine shaft and top cover is prevented by a Huhn-type packing, consisting of carbon rings held against the shaft with garter springs. The rings are of triangular section, and are arranged in pairs in such a way that the carbons are pressed against the sides of the grooves as well as against the shaft. The latter is protected against wear by means of a renewable liner made in two halves bolted together.

Air is admitted to the runner nose via the bores of the generator and turbine shafts, and is thus discharged where it is most required to prevent rough running at low loads. To provide against leakage from the shaft bore, a non-return valve consisting of a rubber-covered copper ball, perforated mild steel housing and gunmetal seat is fitted to the lower end of the shaft, as can be seen in Fig. 8.

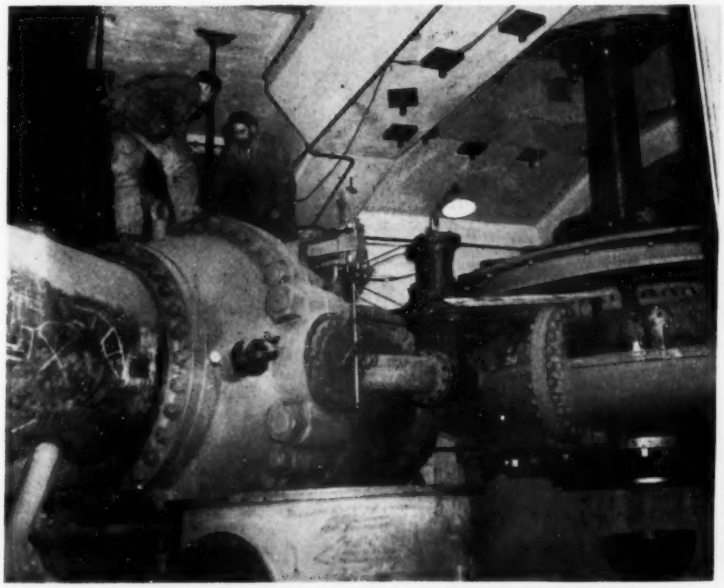


Fig. 11. Turbine and 48 in. rotary inlet valve in course of erection. The 8 in. bypass valve can also be seen

The draft tube consists of an upper conical piece and a grouted-in lining. The conical piece or suction cone is made from mild-steel plate, and is mounted on a split cast-iron base which, in turn, is bolted to the grouted-in lining. This base is easily dismantled, after which the cone can be lowered and removed. It will be readily understood that this arrangement greatly facilitates the usually arduous and complicated job of removing the runner.

The governing system consists of the actuator, servomotor and electrically driven pumping set. The steel band pendulum of the actuator is driven by a synchronous motor supplied direct from a permanent magnet generator mounted on the main alternator shaft. The actuator, which contains its own regulating valve and servomotor, controls the regulating valve of the main guide vane servomotor by means of a spring-loaded connecting rod. The end

of the pilot-valve spindle remote from the actuator pendulum is connected through springs to a rotating piston in a dashpot cylinder, the movement of which is controlled by the return gear from the actuator servomotor. This serves to dampen the movement of the pilot valve and compensates to prevent over correction for speed variations. The amount of damping is controlled by a small valve which is readily adjustable to suit the conditions of operation.

Since the machines at Tungatinah may at times be required to control the system frequency of a comparatively large network, the actuators are supplied with a close regulating device. This device, which is operated by a solenoid, eliminates the actuator damping with the result that very rapid changes in the turbine output can be obtained in the event of small variations in the system frequency.

The actuators are also fitted with an electric motor-driven speed-altering device which is used for synchronising and for adjusting the load on the machine. An electric motor-controlled load limiting device is also fitted to each actuator, and is used for starting and stopping the turbine as well as for limiting the load to a pre-set value. The permanent speed variation gear provides a fixed speed droop between "no load" and full load, which is adjustable from zero to 6 per cent.

Each turbine is supplied with a pumping set to provide the governor and the inlet valve control valves with pressure oil at 285 lb. per sq. in. Each set includes a horizontally mounted electrically driven screw pump (Imo type) fitted to the top of the oil tank and discharging into a pressure receiver. A non-return valve is situated between the pump and the receiver, and an unloading valve is also provided to ensure that when the pressure in the receiver is within the design range, the pump discharges back into the oil tank. When the unloading valve opens, the oil is circulated against no head, and pump power requirements and oil heating are therefore reduced to a minimum. A relief valve is provided to maintain the pressure in the receiver within a safe limit should the unloading valve become inoperative. The correct oil-to-air ratio in the receiver is maintained automatically by an oil-operated compressor with its suction pipe in the oil tank terminating at the normal oil level.

Because of the exacting pipeline conditions, a pressure regulating valve of Boving standard design is supplied with each unit to limit the pressure rise and momentary speed rise on load rejection. The valve is controlled by a pilot valve connected to the governor through a dam designed so that as soon as the governor moves in a closing direction, the pressure regulating valve opens to bypass water to an extent whereby the total flow remains virtually constant. The valve, and in particular the discharge arrangements, are designed to reduce noise and vibration to a minimum.

The turbine inlet valves which were manufactured in Australia by Boving's sub-contractors, Thompsons (Castlemaine) Ltd., are of the Boving rotary type. They are drop-tight under pipeline pressure, and are designed for closing, when necessary, against full unbalanced load. The cast steel rotors have a uniform cylindrical bore of 48 in., and thus offer no obstructions to the water flow between the pipeline and spiral casing inlet. The head loss is therefore no more than it would be for an equivalent straight length of pipe of the same diameter. The bodies of the valves are also of cast steel, and are manufactured in two equal flanged sections which are bolted together. Each valve is operated by means of a servomotor connected to pipeline pressure through a solenoid-operated pilot valve and operating valve —the latter being operated by pressure oil from the governor system. Each valve is also supplied with an hydraulically-operated bypass valve.

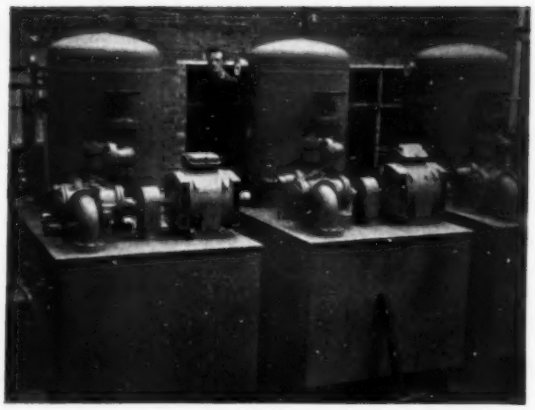


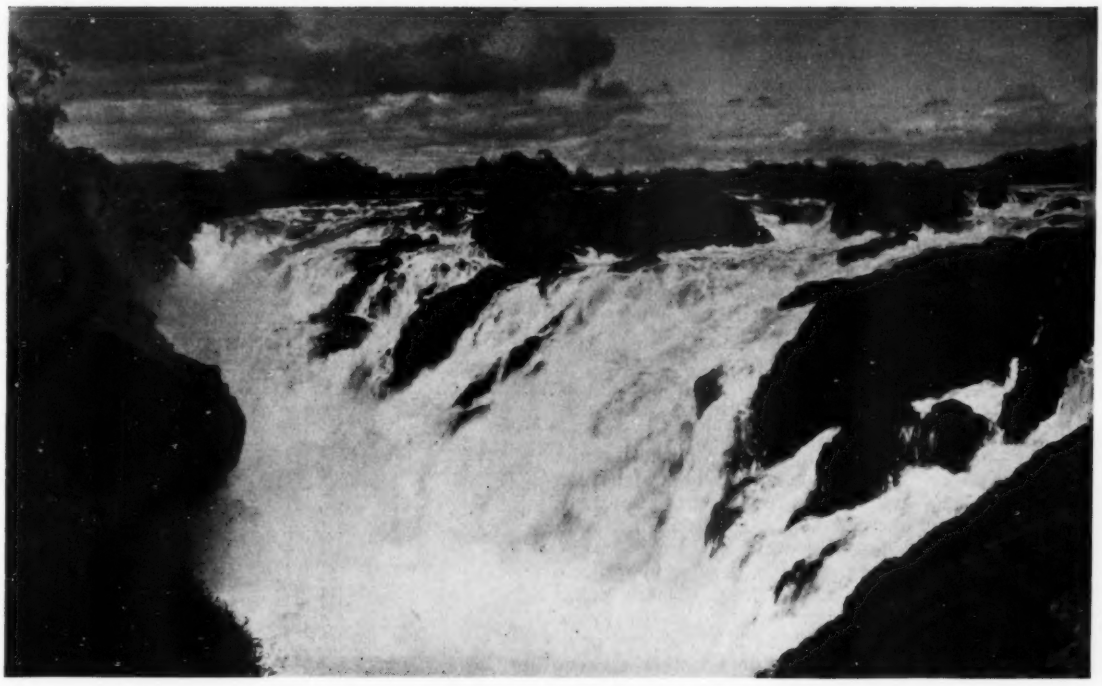
Fig. 12. Pumping sets for governor oil

Cooling Water System

As it is uneconomical to draw relatively low pressure water for cooling purposes from the pipeline, three 10 in. centrifugal pumps have been provided to draw water from the tailrace and discharge into a common cooling water bus pipe. These pumps, supplied by Boving and manufactured by their sub-contractors, Thompsons (Castlemaine) Ltd., have a capacity of 8 cusecs each. They are mounted on the turbine floor (i.e. below minimum tailwater level) and discharge through the common bus to a concrete reservoir situated on the hill behind the power station. The level in the reservoir is automatically controlled between the limits of R.L. 1189 ft. and R.L. 1192 ft. In case of emergency the pumps can discharge direct to the pressure side of the coolers, and as a further safeguard, if the level of the reservoir drops below R.L. 1187 ft., a needle valve connected to one of the penstocks automatically opens. This valve is fitted with a disperser to destroy the energy in the discharge, and is mounted on the wall of the reservoir. It closes automatically when the level reaches R.L. 1192 ft.

Acknowledgment is made to The Hydro-Electric Commission of Tasmania for their help in providing much of the information on which this article is based and we are further indebted to the Commission for permission to publish this description of their most recent development.

Water Control Gates. Publication No. 5/269, issued by Ransomes & Rapier Limited, the original manufacturers of Stoney sluice gates, illustrates and briefly describes a wide variety of water-control installations for which this well-known firm has been responsible.



View of the Lower Falls on the Caroni

The Caroni Scheme

We give brief details of a 150 MW first-stage scheme for which Sir William Halcrow and Partners have been retained as consulting engineers by the Venezuelan Government.

THE river Caroni is one of the main tributaries of Venezuela's principal river, the Orinoco. Roughly 1 km. from the confluence are situated the Lower Falls, depicted above, having a natural drop of 35 m. and presenting an impressive spectacle at all seasons of the year. Normal annual floods are 10,000—12,000 cu. m. per sec., and a catastrophic flood of 40,000 cu. m. per sec. has been estimated.

The Venezuelan Government has decided to build a power station to harness these falls, and has retained the London firm of Sir William Halcrow & Partners as consulting engineers. The neighbourhood is sparsely populated and largely undeveloped, the main local industry being opencast mining of iron ore, which at present is shipped to the United States for smelting. The Government proposes to erect an electrical iron-smelting plant to provide the initial load for the first-stage development on the Caroni, and subsequently to connect up other consumers such as public supply, oil companies, and possibly an aluminium reduction works.

Initially it is proposed to install machines to a capacity of 150 MW, and it is hoped to inaugurate the station by December 1957. With no form of river control upstream it will be possible to guarantee 100 MW continuously and 120 MW for 99·5 per cent. of the time, but plans for the full development of the Caroni have been under consideration for some years. According to these plans the river would be harnessed in four stages and would have a total capacity of the order of 8,000 MW. We hope shortly to publish an article on Venezuela's hydro-electric potentialities.

Estatistica das Instalações Eléctricas em Portugal, 1952. Volume 2. Ministério da Economia Direcção-Geral dos Serviços Eléctricos, Rue de S. Sebastião da Pedreira 37, Lisboa-Norte, Portugal.

The Portuguese Ministry of Economics has now published the second volume of its annual statistics of electricity supply for the year 1952. In tables headed "Public-Utility Hydro-Electric Plants," "Private Hydro-Electric Plants," "Public-Utility Thermal Plants," and "Private Thermal Plants," leading data are given of all generating plants in service in Portugal during that year. Substations form the subject of another table, and a table extending over more than 100 pages follows giving details of electricity supply and consumption in every district in the country. A further table gives particulars of consumption under block tariffs, and the volume concludes with a table of high-voltage transmission lines.

Volume 1 of the 1952 statistics, giving a conspectus of the overall trends during the year, was referred to in an editorial note in our February 1954 issue.

NOHAB Turbine Design Developments

During a recent visit to the works of Nydqvist & Holm, Trollhättan, Sweden, we were given details of a number of interesting features that have recently been incorporated in the design of their water turbines. Of these features one of the most important is a self-lubricating guide bearing. The first turbine having a bearing of this design was placed in service over two years ago, and has been running so successfully that all future NOHAB turbines will have bearings of this design. The value of a self-lubricating bearing in its independence of an external oil pump does not need emphasis.

Referring to Fig. 1, the bearing *a* is surrounded by an oil chamber *b* which is fixed to, and rotates with, the shaft, and consequently carries the oil round with it in the form of a vortex. As it revolves, the oil is forced against a series of tangential intake orifices *c* drilled in an enlarged section at the bottom of the bearing housing, and is thus conveyed to the shaft under the head generated by the rotation. Thence it rises within the bearing sleeve, being assisted by grooves cut helically in the sleeve, to a circular channel *d* in the upper part of the sleeve. At this point the oil is still under sufficient pressure to rise to an oil-flow indicator *e*, whence it descends to an upper stationary oil chamber *f* containing cooling coils *g*. An overflow (not shown) from this chamber returns the surplus oil to the rotating chamber *b*.

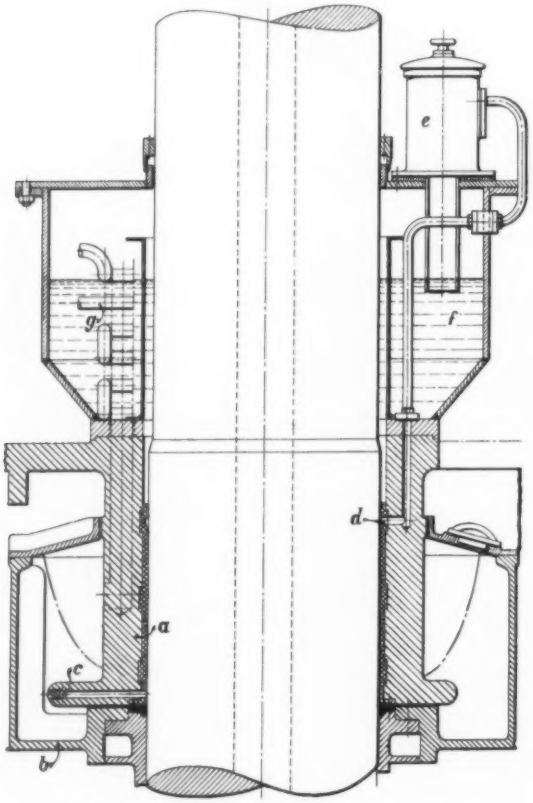


Fig. 1. Self-lubricating turbine bearing

Shaft sealing glands are of the Huhn design, and are now usually of built-up construction, each sealing ring being enclosed in a split stationary ring, these rings being either bolted together or enclosed in a single split housing.

Welded construction is now used extensively, and steel plate is tending to replace cast steel. Of late the joint between spiral casing and stayring has been welded (as at Harsprånget), making casing and stayring virtually a single structure in fabricated steel. Fabricated plate construction is being increasingly used for stayrings and turbine covers, and Francis-type runners are often made with blades in steel plate or cast steel welded to the hub and rim. This method is also to be used for runners made entirely in stainless steel, as for the machines now on order for Stornorrfors. It is believed that the Stornorrfors machines, at 178,000 h.p., will be the most powerful single-unit water turbines in the world.

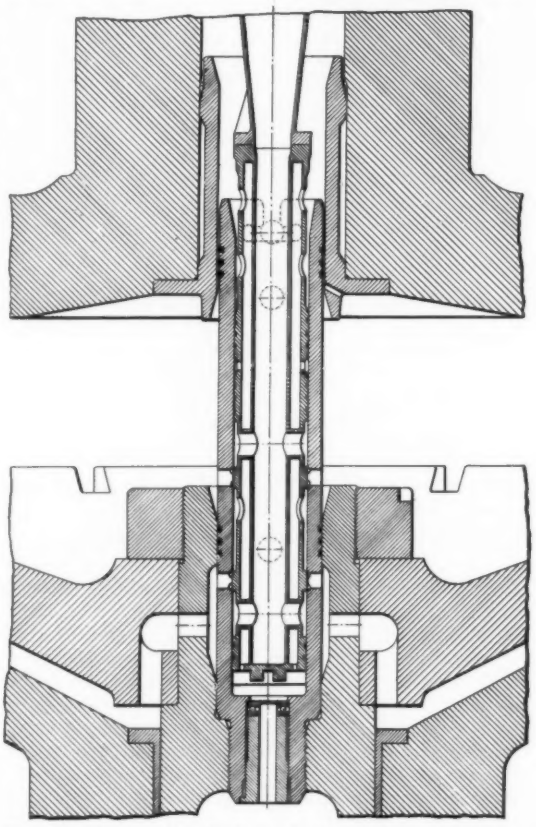


Fig. 2. Concentric design of slidevalve for Kaplan turbines

Turning to Kaplan turbines, the runner servomotor cylinder is now placed either between the turbine and generator shafts or, if space permits, in the runner hub (see Fig. 3). Pressure oil is fed to the servomotor through a hollow rod depending from the combinator and carrying a hollow slidevalve. The rod and slidevalve are non-rotating, and a breaking pin in the com-

binator head protects against damage in the event of seizure and operates an electrical trip to stop the turbine. The valve housing is screwed into the servomotor plunger rod, and can be withdrawn by a special spanner let down through the bore of the turbine and generator shafts. The design of slidevalve now in use is to be replaced by the simpler concentric design shown in Fig. 2.

Two methods of mounting the blades in the runner hub are in use. In that shown in Fig. 3 the trunnion *h* is integral with the lever, and the blade *j* is bolted to the outer face of the trunnion. In the alternative design shown in Fig. 4 the trunnion *k* is integral with the blade, and passes through a ring *l* which is integral with the lever. A bayonet catch *m* is formed on the inside of ring *l* and on the central diameter of the trunnion, so that a partial turn of the blade secures it radially in place, the torque being taken by a number of dowels (not shown) fitted between the blade and the lever. This design tends to speedy removal and replacement of a blade, and leaves the trunnion bearings open for inspection when the blade is withdrawn. In all large Kaplan turbines the discharge ring incorporates an access door leading to a dismantling pit through which the runner blades can be taken.

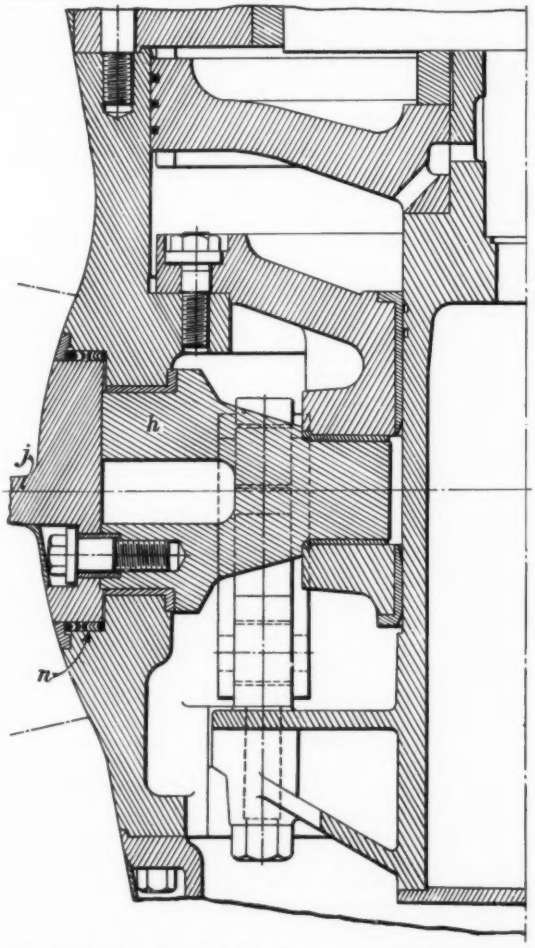


Fig. 3. Kaplan blade fixing using a trunnion integral with the lever

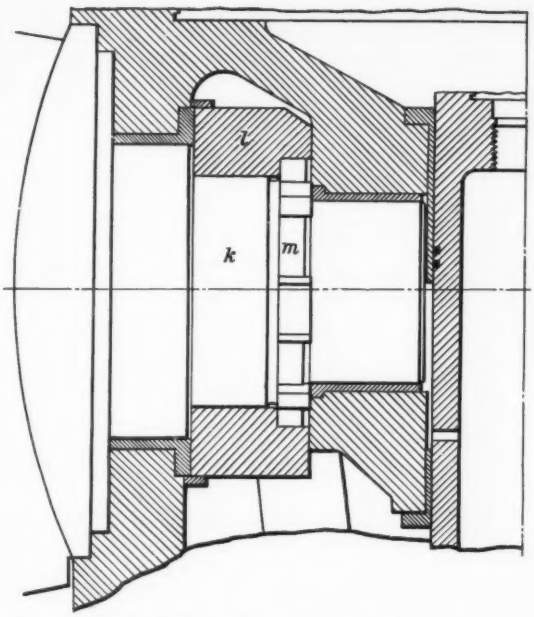


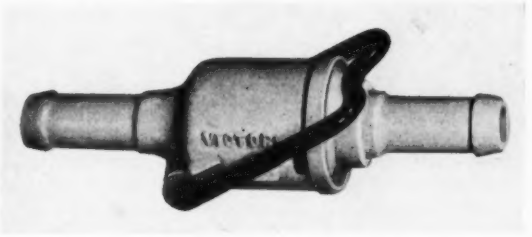
Fig. 4. Kaplan blade fixing using a bayonet catch

Fig. 3 shows at *n* the type of blade-sealing device now usually employed. It is similar to a stuffing box, the packing rings being of a hinge-like shape, two or more of them facing inwards and one outwards, a device being incorporated to reduce the water pressure in the space between the two sets of rings. The packing rings and metal end rings are split so that the packing can be renewed without dismantling the blade.

An important recent development is the adoption of an electro-hydraulic turbine governor designed in collaboration with ASEA. In the ASEA system, which was described in our October 1952 issue, the usual pendulum is replaced by purely electrical controls. The first governor of this type was installed at Midskog in June 1950, and amongst other important stations using this system may be mentioned Harsprånget. When in Sweden we saw an ASEA/NOHAB governor in operation at Storfinnforsen, and received the most excellent accounts from the station staff of its standard of performance.

Self-Sealing Air-Hose Coupler

Instantaneous self-sealing with no leaks is claimed for a new type of air-hose coupler now being produced by Victor Products (Wallsend) Ltd., mining



The Victor self-sealing air hose

and industrial machinery manufacturers, of Wallsend-on-Tyne, Northumberland. The coupler is designed for high- and low-pressure air hoses, and incorporates a rubber seal ring with a simple action. The stem of the coupler is inserted into the spud, air is turned on, and this causes the rubber ring on the stem to rock forward giving the initial sealing action. As the air pressure is increased so the complete sealing action is effected.

The Victor coupler requires no spanners or tools to couple or uncouple. It cannot be uncoupled accidentally, or deliberately while under working pressure. An additional safety factor is a spring bridle which holds the two parts together, and has been designed to allow the stem to rotate within the spud for the removal of kinks and twists in the host. The rubber sealing ring is completely protected from damage and is stated to have a long life, but to be simple and cheap to replace.

Victor Products (Wallsend) Ltd. are offering potential buyers a one-month free trial of any one size of coupler. The range being manufactured covers hose sizes of $\frac{1}{2}$ in., $\frac{3}{4}$ in. and 1 in. as hose-to-hose coupler or compressor-to-machine coupler. The coupler stem is manufactured in three styles, and there are seven styles of spud fittings.

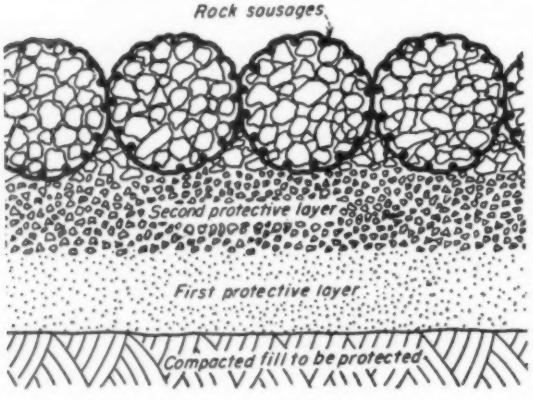
Abstracts from the World Technical Press

The Colunga 220/150/60 kV Substation

A full description is given of the installations of the new switchyard and transformer station at Colunga, which constitutes one of the major centres of the Italian 220 kV grid, and distributes energy to the consumption districts of Eastern Emilia and Romagna, Bologna, Ferrara and Ravenna. It is supplied from the Piave-Boite-Vajont plants through the Soverzene power station and is, besides, connected with the main generating centres in Northern Italy. (Dott. Ing. Marino Valtorta, *Tecnica Italiana*, Vol. IX, No. 2, March 1954, p. 99, 11 pp., 12 ff.)

Anti-Erosion " Rock " Sausages

An account is given of the tests made at Iowa City, Iowa, and Allenspark, Colorado, with a view to protecting earth embankments from swift flowing waters. The use of the sausage-type of anti-erosion construction was suggested by Chinese practice on the Yellow River, and a similar construction, with wire, which has been for many years in use in India in torrential streams carrying monsoon run-off from the southern slopes of the Himalaya. The sausages developed at the Iowa Institute of Hydraulic Research are made of tubes of spiral-woven wire fencing tightly stuffed with crushed rock, and laid on a blanket of graded material. For permanent installations, it is likely that heavily galvanised or even stainless-clad wire would have to be used. A life of 15 years under Indian conditions is reported by F. P. Anderson for galvanised wire of No. 6 B.W.G.; the sausages referred to were 5 ft. in diam., and 50 ft. in length. If safety were a prime requisite, as for a spillway over the top of an earth dam, a double layer of sausages would be highly desirable. In any case the rock gradings in the sausages and in the layers under them are extremely important. The sausages should lie along the direction of the flow, should be fastened together at closely spaced intervals, and should cover the entire area subject to erosive velocities without any holes or " skips." (C. J. Posey, *Engineering News-Record*, May 13, 1954, p. 45/6, 2 ff.)

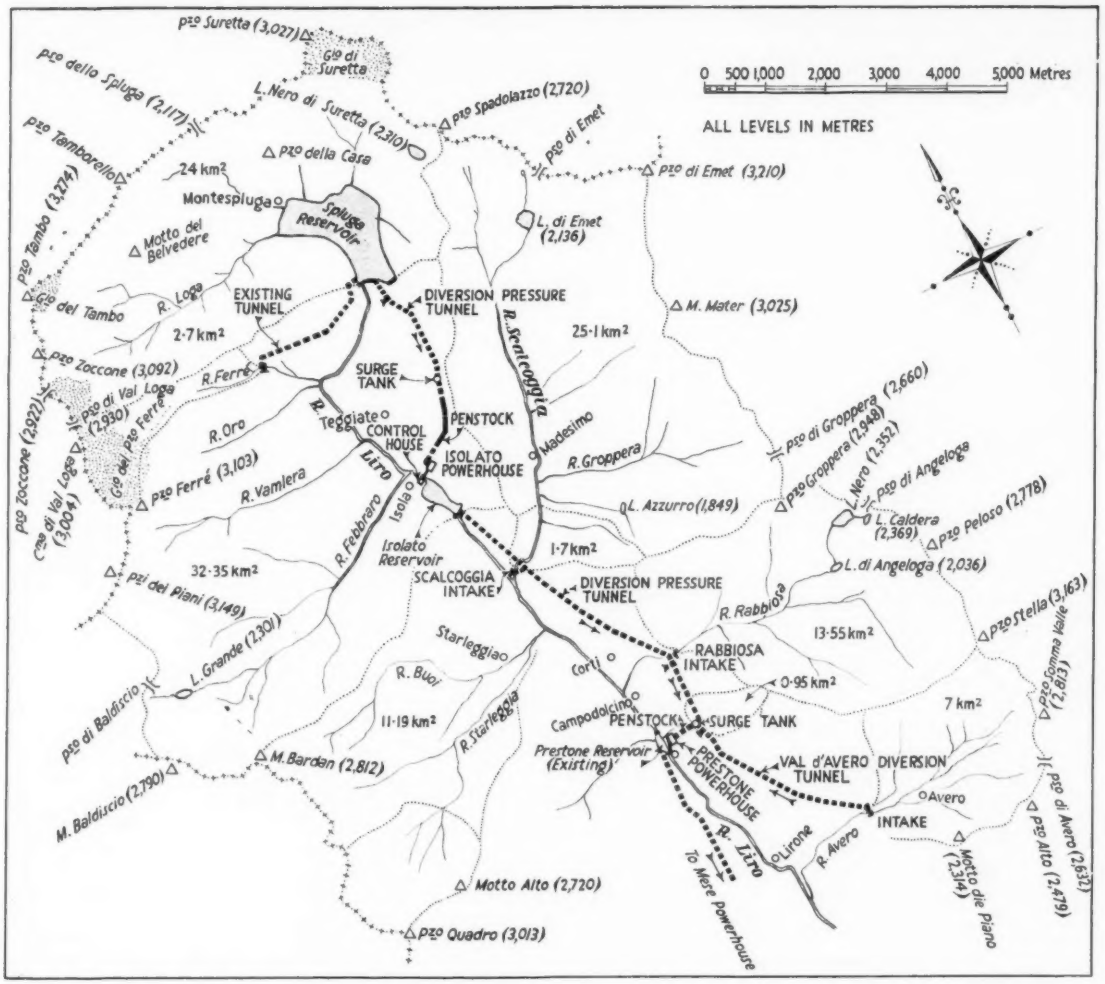


Tidal-Plant Turbines

This article reproduces a paper read on June 19, 1953, at a meeting of the Société Hydrotechnique de France. With the Rance estuary project, the harnessing of tidal energy in France has reached the stage at which development appears possible in the very near future. One of the main difficulties to be overcome lies in the very wide range of heads under which the turbines must operate. Although the possibility of manufacturing turbines for this type of development is now established beyond all question, it is impossible to determine conclusively which of the turbine designs considered would supply the maximum energy under given tidal and operating conditions. In other words, the problem has been reduced to the question: Which of the various efficiency curves suggested, all conditions being otherwise equal, would, in practice, produce the greatest number of kWh? The author deals with the problem from its various aspects, with the help of graphs. By means of a few examples applied to the Rance estuary project, the author shows the considerable repercussion on power production which may result from the choice of characteristics in apparently closely similar turbines. (R. Girat, *La Houille Blanche*, Vol. 9, No. 1, January-February 1954, p. 64, 11 pp., 11 ff.)

Liro Development, Italy

Two plants recently added to the existing installations of the Edison Group in the Liro-Mera Valley, are described—Isolato and Prestone, which utilise the first and third falls of the Liro River respectively. The Isolato dam is an arched cantilever structure, 40·5 m. in maximum height above foundations, with a crest span of 66·4 m. and having a thickness varying between 3·90 and 2·06 m.; the volume of concrete involved, abutments included, is 7,100 cu. m. The reservoir created by this dam ensures during the



greater part of the year the weekly regulation of the catchment area of the third fall, acting besides as an afterbay to the Isolato plant and a forebay to Prestone. The alternators of the Isolato underground power house are driven by double Pelton wheels, those of the Prestone open-air plant by Francis turbines the discharge from which flows into the existing Prestone reservoir which supplies power water to the San Francisco plant. The expansion-chamber type surge tanks have the following main measurements: 52·4 m. high by 2·5 m. diameter at Isolato, 49·162 m. high by 4·5 m. diameter at Prestone. A map of the development is given above. (*L'Energia Elettrica*, Vol. XXXI, March 1954, p. 206, 8 pp., 13 ff.)

A Heavy Excavation Programme

At the Roanoke Rapids on the Roanoke River, North Carolina, a relatively low dam is being built at the head of the rapids and a long deep tailrace is being formed. The power house being built now for Virginia Electric and Power Company will occupy a 70 × 230 ft. hole, 72 ft. deep, while the tailrace, which will be 8,000 ft. long, will be 80 ft. wide and 56 to 31 ft. deep. All this excavation work is being conducted in solid granite and is justified in order to get full hydraulic advantage out of the long rapids at the least cost. At the cost of excavating about a million cu. yards of granite a 74·5 ft. operating head will be obtained and drive four 35,000 h.p. turbines. To tackle rock excavation of such an extent, some interesting methods were introduced. A drill carriage, mounting 14 wagon drills abreast, has been pushed along on rails to drill holes for the first lift of the tailrace throughout its length. This rig, a kind of jumbo for moving the wagon drills simultaneously, is shifted on blocked-up rails and positioned to drill holes 24 to 30 ft. deep and 5 to 7 ft. apart. Each blast breaks up a 24 ft. depth over an area measuring 40 by 102 ft. After the first lift has been blasted and mucked clean, the jumbo, owing to the rough and uneven rock surface, is replaced by individual wagon drills which are moved independently through the second-lift blasthole positions. Second and third lifts bring the tailrace excavation down to its greatest depth—56 ft. at the upstream end. A 7 cu. yd. electric shovel is being used for loading the rear-dump trucks that haul out the muck. Though used in a dike built parallel to the tailrace to keep out the river flow, the excavated granite is not suitable for use as concrete aggregate for the dam. An outside supply was therefore neces-

sary, and 8,300 ft. of railroad track had to be built to transport this material to the storage piles. A belt conveyor riding in a reclaiming tunnel feeds the batching plant. Concrete for the 3,000 ft. long dam, made of the purchased aggregate sized to 6in., has 1,800 lb. per sq. in. strength inside the structure and 2,500 lb. per sq. in. strength near the faces. The mixing plant is capable of turning out 5,000 cu. yards per day or better. Cement, hauled in by rail in bulk, is moved to silo storage on an air slide; this is an inclined conduit with a canvas division. Air moves through the conduit under the canvas partition, causing the cement to slide along on its top side. The dam will contain just over a quarter of a million cu. yards of concrete, of which 50,000 cu. yards has been placed since work started. The river flow, averaging about 20,000 cusecs and reaching as high as 45,000 cusecs, has presented no unusual diversion problem. The general eastward course of the river at this point was turned north by earth cofferdams and kept over on the left side of the rapids while the power house and tailrace excavations were proceeding near the right bank. Remaining diversion work during construction will be accomplished by straightforward channel-shifting operations, using earth cofferdams and temporary sluices cast in the dam for the purpose. Upon completion, the normal depth of water against the upstream face of the dam will be 62 ft. Present scheduling calls for the first of the four 27,800 kVA units to go on the line next June, the fourth being due to turn in December 1955. The turbines will be adjustable-blade propeller type, running at 128·6 r.p.m., and the generators will be enclosed in a semi-outdoor type of station. Total cost of the project will approximate £12 million, of which roughly one-third will have been spent on excavation. (*Engineering News-Record*, Vol. 163, No. 4, July 22, 1954, p. 31, 4 pp., 6 ff.)

Ganguwal Power Station

This plant is No. 1 power house of the Nangal Hydel project, and its construction involved the awkward problem of dewatering pits into which foundation concrete had to be poured 68 ft. below the subsoil water table. The procedure applied to this task is described in detail. (A. N. Malhotra and Harbans Singh, *Irrigation and Power*, Vol. II, No. 1, January 1954, p. 62, 23 pp., 20 ff.)

Venturi Setting in Surge-Chamber Systems

We have here to deal with a new contribution by Prof. Escande to the study of stability in surge-chamber systems. As in the analysis written in collaboration with Professor R. Huron and published in WATER POWER, September 1953, p. 338, the system investigated consists of two surge chambers, the one set up at the downstream end of the supply tunnel, and the other at the upstream end of the tailrace tunnel. In this instance, however, the tunnel connecting with either surge chamber has a contraction similar to that of a Venturi tube, hence the term "Venturi Setting." With regard to the tailrace surge chamber, this Venturi setting is purely hypothetical, since it does not normally occur in actual practice; it is incorporated in the computation solely for the purpose of giving the formulae arrived at a character of generality. The fundamental ratios, as well as the equations are worked out on the same lines as followed in the analysis mentioned above, and several examples of numerical applications, are added. The author demonstrates that the provision of a Venturi setting in the tailrace surge chamber of a two-chamber system would conduce to a lowering of the hydraulic stability of the structure; a system of this pattern should therefore be ruled out. Actually in hydro-electric plants, only the surge chamber of the supply tunnel is equipped with a Venturi setting, and the formulae applicable to this particular instance can easily be deduced from the author's general analysis. (Prof. Escande, *Le Génie Civil*, Vol. CXXXI, No. 12, 15.6.54, p. 228, No. 13, 1.7.54, p. 245, 5 pp., 9 ff.)

Automatic Hydro Plant

Tenkiller Ferry plant, part of a Corps of Engineers multi-purpose project on the Illinois River, Oklahoma, is connected to Fort Gibson plant, another of the Corps' multi-purpose projects on the Grand River, by a 30 mile 154 kV transmission line which interconnects with the Oklahoma transmission network. The Tenkiller-Fort Gibson line handles the power-line carrier for supervisory and load-control functions that regulate the unattended Tenkiller plant. Carrier intelligence bypasses the switching station. For normal operation, the "supervisory-local" control switch at Tenkiller is maintained in the supervisory position, so that the Fort Gibson operator may start either or both 17,895 kVa Tenkiller generators in sequence. Units are automatically brought up to speed and synchronised to the transmission line. Plant loading may then be controlled manually by supervisory, or automatically by load frequency. Under automatic load control, the Tenkiller plant will operate as if it were another generator at Fort Gibson, the generators at both plants responding to load changes simultaneously and in proportions predetermined by the equipment ratio adjustments. Similar load-control equipment is being manufactured for the Corps' Norfolk hydro-electric plant on the North Fork of the White River in North Arkansas. (H. W. Claybaugh, *Electrical World*, Vol. 141, No. 23, June 7, 1954, p. 20, 1 f.)

CLASSIFIED ADVERTISEMENTS

Announcements for this column can be accepted up to the 8th of the month for the following month's issue. The charges are fourpence per word with a minimum of 10s. Box No. facilities 2s. 6d. extra. In order to avoid accountancy it would be appreciated if instructions to insert were accompanied with remittance.

Appointments Vacant

TRAINING IN DRAUGHTSMANSHIP is offered to men between the ages of 21 and 25 who have three years' engineering workshop experience and education to O.N.C. Standard (Mech.). Successful candidates will receive a period of paid training and on satisfactory completion will be offered employment in one of our Drawing Offices engaged on Steam and Water Turbine, and Heavy Oil Engines. Training and subsequent employment will be at the Rugby Works of THE ENGLISH ELECTRIC CO. LTD. Apply with full details of age and experience, etc., to Dept. C.P.S., 336/7 Strand, W.C.2, quoting Ref. 159A.

ENGLISH ELECTRIC have vacancies for design engineers in their Water Turbine Department at Rugby. Applicants should be qualified mechanical engineers who have served a recognised apprenticeship in heavy engineering and have several years' drawing office or design experience. Previous experience of centrifugal pump design might be an advantage. Write giving full details to Ref. 804K, Dept. C.P.S., 336/7 Strand, W.C.2.

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